A Thesis on

Design and Implementation of an Isolated Solar Photovoltaic Power Generation System

Submitted by

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Design and Implementation of an Isolated Solar Photovoltaic Power Generation System

A Thesis Submitted in Partial Fulfilment

of the Requirements for the Award of the Degree of

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In

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(Industrial Electronics)

Submitted by

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CERTIFICATE

This is to certify that the project report entitled "Design and Implementation of an Isolated Solar Photovoltaic Power Generation System" being submitted by Rupesh Patel (212EE5399), Department of Electrical Engineering, National Institute of Technology Rourkela, Rourkela on partial fulfilment of the requirements for the award of the Degree of Master of Technology in Industrial Electronics specialisation, Department of Electrical Engineering, National Institute of Technology Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matters embodied in this Project Report have not been submitted to any other University or Institute for the Award of any other Degree or Certificate.

Date

Dr. MONALISA PATTNAIK

Department of Electrical Engineering

National Institute of Technology, Rourkela

DEDICATED

TO

MY RESPECTED PARENTS

AND

MY BROTHER MUKESH

ACKNOWLEDGEMENTS

With a deep sense of gratitude, I wish to express my sincere thanks to my guide, Dr. MONALISA PATTNAIK, Department of Electrical Engineering, National Institute of Technology, Rourkela for giving me the opportunity to work under her on this project. I truly appreciate and value her esteemed guidance and encouragement from the beginning of this project and putting this thesis together. I am extremely grateful to her. Her knowledge and company at the time of crisis would be remembered lifelong.

I want to thank all my teachers for providing a solid background for my studies and research thereafter. They have been great sources of inspiration to me and I thank them from the bottom of my heart.

I will be failing in my duty if I do not mention the laboratory staff and administrative staff of this department for their timely help.

I also want to thank my parents. I would like to share this moment of happiness with my parents and brother. They rendered me enormous support during the whole tenure of my stay in NIT Rourkela.

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RUPESH PATEL

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ABSTRACT

Solar photovoltaic power generation system is one of the burning research fields these days, even governments are also making plans toward increasing the amount of power generation from renewable energy sources because in future viability and crisis of conventional energy sources will increase. Further government liberalisation and technical developments encourage the use of renewable sources for power generation in terms of distributed generation system. In order to rigging the present energy crisis one renewable method is to develop an efficient manner in which power extracts from the incoming son light radiation calling Solar Energy. This thesis deals with the design and hardware implementation of a simple and efficient solar photovoltaic power generation system for isolated and small load up to 5 KW. It provides simple basic theoretical studies of solar cell and its modelling techniques using equivalent electric circuits. Solar Photovoltaic (PV) power generation system is comprising several elements like solar panel, DC-DC converter, MPPT circuit, Battery charge controller and load, these subsystems are designed in Proteus software and DC-DC (Boost) converter, MPPT circuit using microcontroller and sensors adopting perturbation and observation method, Battery charge controller and single phase inverter for AC loads are implemented in hardware in simple manner.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATED WORDS

I_{ph}	Photon generated current
I_d	Current through Diode
P	Power
KW	Killo Watt
mW	milli Watt
η	Efficiency
PV	Photovoltaic
PWM	Pulse Width Modulation
MPPT	Maximum Power Point Tracking
P&O	Perturb and Observe
ADC	Analog to Digital Conversion

Chapter 1

Introduction

1.1 Overview on Need of Solar Power Generation

In the field of power sector in these days one of the major concerns is day-by-day increasing more power demand but the quantity and availability of conventional energy sources are not enough resources to meet up the current day's power demand. While thinking about future availability of conventional sources of power generation, it is become very important that the renewable energy sources must be utilized along with source of conventional energy generation systems to full fill the requirement of the energy demand.

In order to rigging the current day's energy crisis one renewable method is the method in which power extracts from the incoming son radiation calling Solar Energy, which is globally free for everyone.

Solar energy is lavishly available on the earth surface as well as on space so that we can harvest its energy and convert that energy into our suitability form of energy and properly utilize it with efficiently. Power generation from solar energy can be grid connected or it can be an isolated or standalone power generating system that depends on the utility, location of load area, availability of power grid nearby it. Thus where the availability of grids connection is very difficult or costly the solar can be used to supply the power to those areas. The most important two advantages of solar power are that its fuel cost is absolutely zero and solar power generation during its operation do not emanate any greenhouse gases. Another advantage of using solar power for small power generation is its portability; we can carry that whenever wherever small power generation is required.

In the last few years the power conversion mechanisms for solar energy has been significantly comes in compact size. The advance research in the field of power electronics and material science have greatly helpful for engineers to develop such a system that very small but effective and powerful systems that have capability to withstand for supplying the high electric power demand.

For every country day by day power density demand is increasing. Solar power generation have also the capability to handle the voltage fluctuation very effectively by setting the system for the use of multiple input converter units. But in solar power generation system due to its high installation cost and the low efficiency of the solar cells, this power generating systems can hardly participate in the competitive power markets as a main renewable source of power generation.

Scientists are constantly trying to improve in the field of development of the solar cells manufacturing technology for increasing efficiency. That will definitely help to make the solar generation as in habit for use in daily life as prime renewable source of electrical power on a wider range basis than present day conditions. In solar power generation system the latest power control mechanisms is using now these days calling the Maximum Power Point Tracking frequently referred as MPPT, it has guide to the increase in the efficiency of operation of power generation from the solar cells. Thus MPPT is most important in the field of consumption of renewable sources of energy [1].

1.2 Motivation

The key motivation is fascinating the scientists more to research in this field. Now this field is become burning research fields these days. A key point for encouraging to the use of solar PV power generation system across the whole world wide many of the Governments giving centre of attention to their investments in renewable and clean energy sources for developing their power sector areas because every country have limited sources of conventional energy. Even in the India government also aims to achieving generating capability of 20GW from solar energy by year 2020 and 40% of it will generate by solar PV power generation system according to draft report of JNNSM (Jawaharlal Nehru National Solar Mission) MNRE, India.

Power generation method from solar photovoltaic module is a foremost effective technique of using the solar energy. In this method solar panel directly convert sunlight irradiation into electricity by the photovoltaic effect, and it has spacious scenario for improvement with a number of advantages like clean and pollution-free due to solar power generation do not releases any greenhouse gases in its operation, easy in structure and free from noise pollution due to it does not contain any moving parts, no fuel cost required because it uses son light as a input that is globally free, little maintenance and renewable [1]. Solar power generation have low conversion efficiency and high installation cost therefore our target should be increases the efficiency for power generation from the system. Researchers are continuously searching to develop better and efficient solar cell materials and give service to minimise the cost for power consumers of solar systems.

While thinking of designing part of this project we need designing software like Matlab, Labview, Multisim, PSpice and Proteus etc. Proteus is especially attracted me because while executing condition of program or circuit functions, we can switching the circuit or changing the operating mode of designing and also one lab class on Proteus is taught in first year of M-tech.

These days microcontrollers are coming with its development board kit, on that board many supporting connection circuit with the microcontroller are there, one of the advanced development board is Arduino complete development board kit. It has many advantages and ACS712 current sensor Hall Effect based [22] have good resolution and available in different ranges of current in lowest cost which are very efficient and easy for hardware implementation.

1.3 Objective

The mainline objective of this project work is to – "Design and hardware implementation of an isolated Solar PV power generation system for small load rating Up to 5 KW". And this objective is further divided into following parts for simplicity of implementation.

- To Design of Solar panel in Proteus software.
- To design and implementation of a DC-DC (Boost) converter using Proteus software.
- To design of a battery charge controller in Proteus and its implementation.

- To design MPPT circuit using microcontroller and sensors in Proteus and its implementation.
- To develop C code for P&O MPPT algorithm using Keil software for Proteus software execution.
- To design and hardware implementation of a single phase solar inverter.

1.4 Thesis Organization

This thesis is organized in chapter wise as follows:

Chapter 1 An overview on why we have to increase power generation from renewable energy sources. Glance over advantages of solar PV power generation system. Motivation for this project with mainline objective is divided into subparts.

Chapter 2 An overview on solar cell, its basic theory, connections, technologies and modelling. Design of a solar panel in Proteus is described.

Chapter 3 About DC/DC converter especially Boost converter and its need in solar power generation are described. A design of Boost converter in Proteus software is shown with its hardware implementation.

Chapter 4 Small introduction on MPPT and its importance in solar PV power generation is given. What are the MPPT's requirements described. Its circuit design on Proteus and hardware implementation is shown.

Chapter 5 About Battery charge controller, its reason for need and its functions are described. A proposed battery charge controller is designed in Proteus and its hardware is implemented.

Chapter 6 A proposed single phase non sinusoidal inverter for isolated system is designed on Proteus and its hardware is implemented.

Chapter 7 Conclusion and scope of further to work is presented.

Chapter 2

Solar Panel Design in Proteus

2.1 Solar Cell Overview.

2.2 Modeling of Solar Panel in Proteus.

2.1 Solar Cell Overview

A solar cell is an electronic device that converts the light energy directly into electric energy without any form of moving parts by using photovoltaic effect.

Fig. 2.1 Solar Cell

- A Solar cell is also calling Photovoltaic (PV) Cell.
- It is a static device, no moving part.
- “Photo” means Light and “voltaic” means producing electricity.
- It is a solid state electronic device made of semiconductor materials like silicon.
- Solar cell converts energy of light directly into Direct Current (DC).
- Solar cell does not use heat of light to produce electrical energy.
- In 1839 the photovoltaic effect was discovered, in 1883 first thin film solar cells fabricated and the first practical photovoltaic cell was developed in 1954.
- Efficiency of solar cell depends on many factors like shading on cells, irradiance, temperature etc.
- In 2014 the highest 44.7% efficiency has achieved by using the multiple junction cells.

2.1.1 Basic Theory of Solar Cell

Solar cells are made by two types of semiconductor materials one is N-type semiconductor and other is P-type semiconductor material for generation of electricity [2].

- When light strikes on semiconductor, it generates electrons (-) and holes (+) pairs.
- when electron and hole pair reaches between two different type of semiconductor's joint surface then electron and hole are separated, electron is attached by N-type semiconductor and hole is attached by P-type semiconductor after that they are not rejoin due to joint surface do not allow both way traffic.

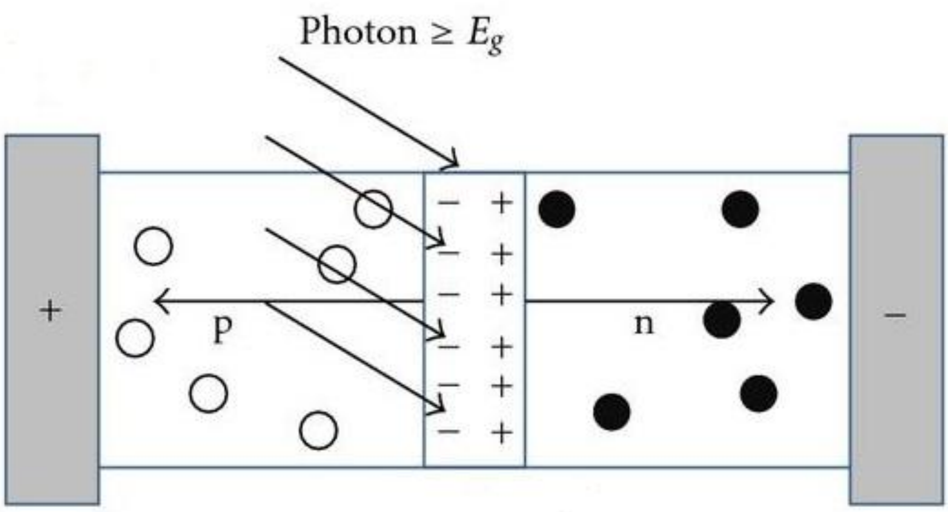


Fig 2.2 P-N junction illustration of PV cell

- Now electrons are contained by N-type semiconductor and holes are contained by P-type semiconductor, an electro motive force (emf) is generated in electrodes.
- When these electrodes are connected together by a conductor electrons run toward O-type semiconductor and holes run toward N-type semiconductor.

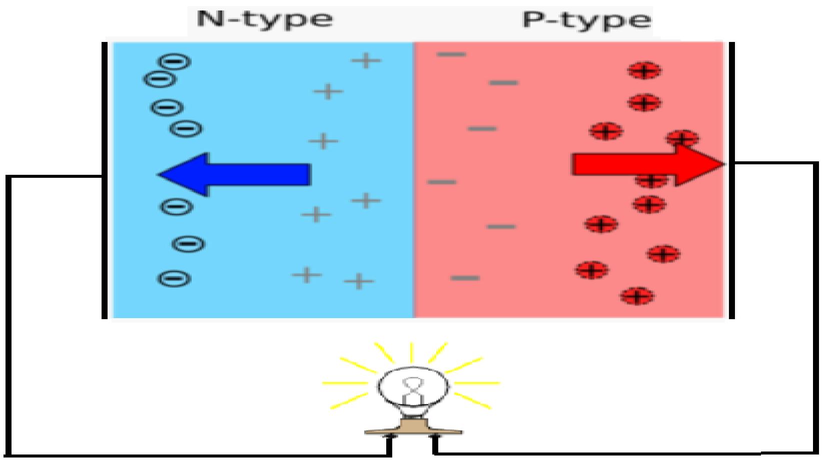


Fig. 2.3 Flow of current

2.1.2 Solar Cell Connections

Solar cell connection is just like battery connection. When positive terminal of one solar cell is connected to negative terminal of another solar cell then they form series connection. In series connection current is same for all cells and voltage is added by each cell shown in figure 2.4.

And when all positive terminals of solar cells connected to one terminal and all negative positive terminals of solar cells connected to another one terminal then forms parallel connection. As shown in figure 2.5 here current is added and voltage is same for all cells.

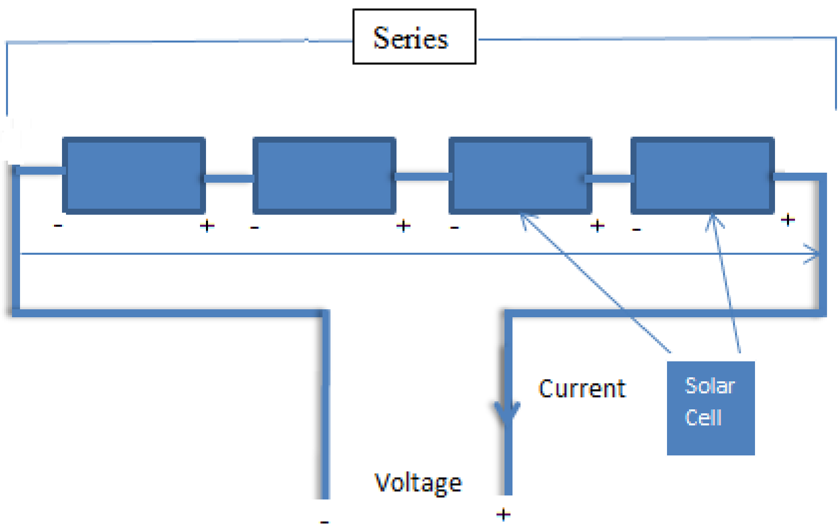


Fig 2.4 Series connection of solar cell

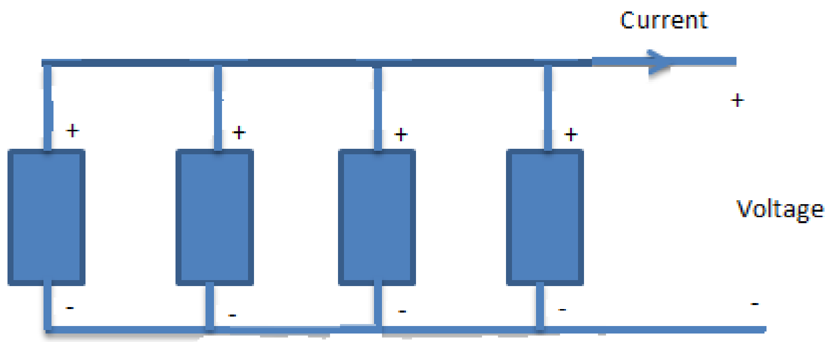


Fig. 2.5 Parallel connection of solar cell

2.1.3 Solar Cell Technologies

Solar cell is manufacturing by different materials. The two major technologies are wafer-based silicon and thin-film [3].

Crystalline silicon solar cell is more efficient than thin-film solar cell but that is more expensive to produce. They are most commonly uses in large to medium electric applications like grid connected PV power generation.

Mono-crystalline solar cell is manufactured by pure semi-conducting materials so it has higher efficiency (above 17% in industrial production and 24% in research laboratories [4]. Poly-crystalline solar cell is slightly less efficient than Mono-crystalline but less in cost.

In thin-film solar cell very thin layers of semiconducting materials are uses so they can be produces in large quantity at lower cost but it efficiency is less. This technology is uses in calculators, watches and toys etc.

There are too many other PV technologies available like Organic cells, Hybrid PV cells combination of both mono crystalline and thin film silicon etc.

2.1.4 Solar Cell, Solar Module or Panel and Solar PV Array

In solar power generation system number of solar cells is required to produce high power so they are connected in form of Solar Module or Solar panel and for higher capability form Array as shown in figure 2.6

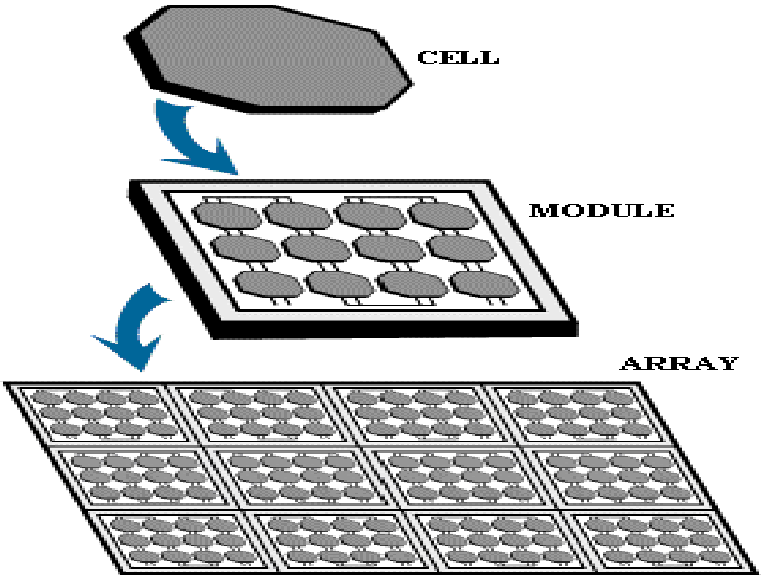


Fig. 2.6 Formation of solar Module and solar PV Array

2.1.4.1 PV Module

A solar panel or module is a group of connected solar photovoltaic cells electrically and mounted on a sustaining structure. A photovoltaic module is a systematical arranged series connection of solar cells.

2.1.4.2 PV Array

A solar array is a group of solar photovoltaic panels or modules connected electrically together and mounted on a sustainable structure to produce higher amount of power. For this project the main task is to design a stand-alone power generation system for a small load like a house situated on hilly area or for any small load that is not connected to grid network. For this kind of loads design such a system that uses the power generated from PV Array and convert it into AC for AC loads or stores it in storage element with efficiently and paralleling supplies the load. In this project Vikram solar panel is used so not need to bother about solar PV Array implementation.

2.1.5 Solar Cell Modeling

From the physical heavier and mechanism of a solar cell an equivalent electrical circuit is derived [5], worldwide two different circuit are accepted as equivalent electrical circuit of solar cell [6, 7], the first one is a simplified model of a single solar cell that exhibits an approximate characteristic of a solar cell and second one having two diodes combination one for reflecting diffusion and other for carrier. The equivalent circuits are shown in figure 2.7 and 2.8 below.

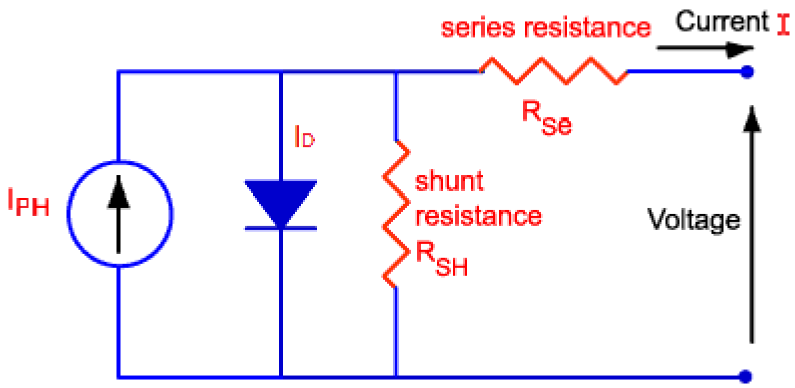


Fig. 2.7 Equivalent circuits of solar cell

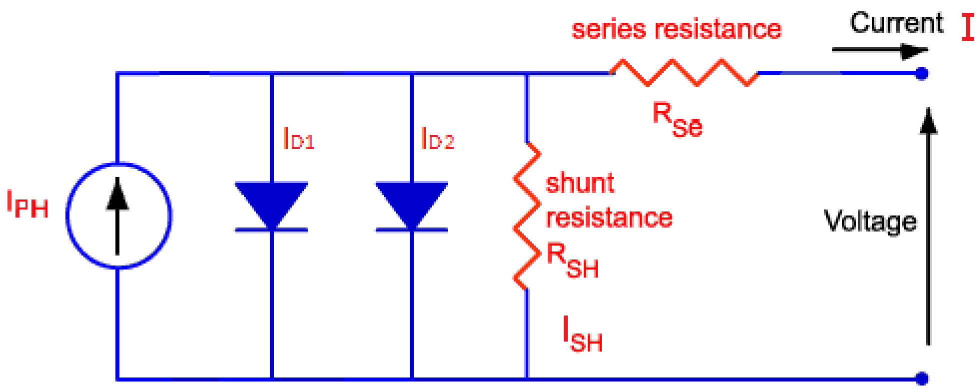


Fig. 2.8 Equivalent circuits with dual diode of solar cell

Applying node equation in figure 2.7(a), where I_{PH}, diodes, R_{se} and R_{sh} are meeting together.

$$I_{PH} = I_D + I_{SH} + I \tag{2.1}$$

$$I = I_{PH} - I_D - I_{se} \tag{2.2}$$

$$I = I_{PH} - I_{sat1}\left(e^{\frac{q(V+I*R_{se})}{KT}} - 1\right) - I_{sat2}\left(e^{\frac{q(V+I*R_{se})}{2KT}} - 1\right) - \left[\frac{V+I*R_{se}}{R_{SH}}\right] \tag{2.3}$$

When both diodes are combined together then equation is become

$$I = I_{PH} - I_{sat}\left(e^{\frac{q(V+I*R_{se})}{AKT}} - 1\right) - \left[\frac{V+I*R_{se}}{R_{SH}}\right] \tag{2.4}$$

Where A is ideality factor and takes the value between 1one and 2. [5, 6, 7]

2.1.6 I-V Characteristic Curve of a Solar Panel

A PV module produces maximum current when it's positive and negative terminal is shorted, this maximum current is named as I_{SC} short circuit current of PV panel. When panel is short circuited, it's voltage across terminal is zero.

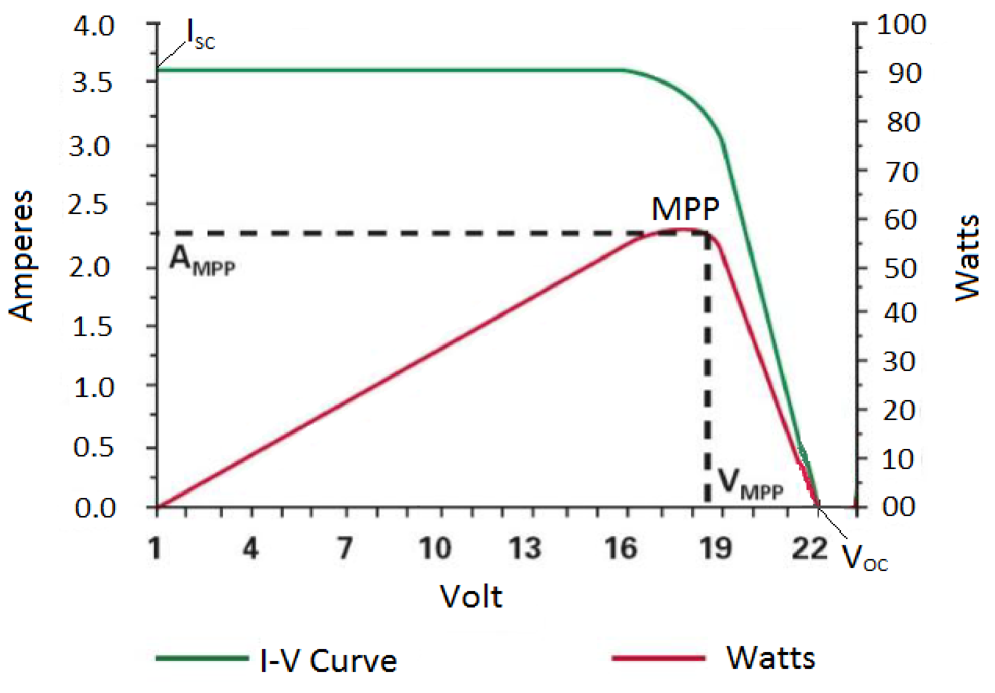


Fig. 2.9 Standard I-V Characteristic of a Solar Panel

When panel terminal is kept open circuited then the voltage across its terminal is maximum called open circuit voltage V_{OC} of that panel. This time panel fells infinite resistance since the current is zero this time. Between these two extremes point under different load resistance condition different pair of points of current and voltage are achieved, by connecting points a curve is find called I-V curve. This curve is called I-V characteristics of that particular panel. Figure 2.9 showing the I-V curve with the output power curve.

As showing in figure 2.9 V_{OC} is occurred when current is zero and I_{SC} is occurred when voltage is zero on that curve and power of that panel at any point in Watt is calculated by multiplying both the current and voltage of that point.

2.1.7 Impact of Solar Irradiation on I-V Characteristic of a Solar Panel

Highest solar irradiance on the earth ground level is 1000 W/m^2. If the solar irradiance is decreases due to cloud, the earth movement or any other reason will reduce the output current of the solar panel because of the I_{PH} is directly proportional to the sun irradiance while the variation on voltage is much smaller as shown in Figure 2.10 [8].

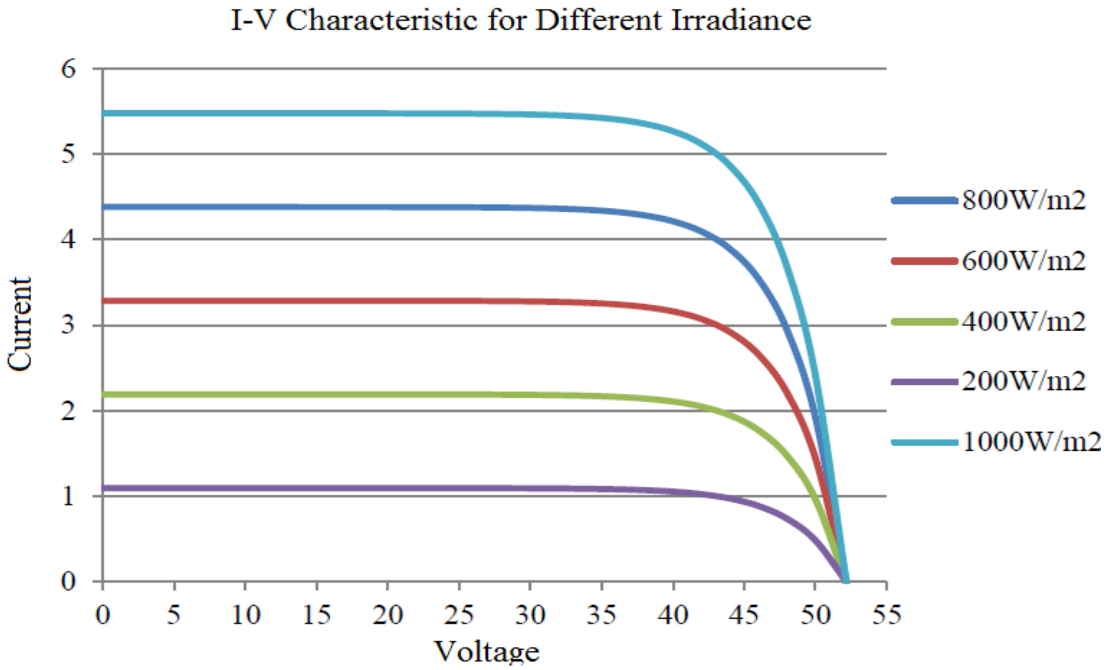


Fig. 2.10 effect of solar irradiation

2.1.8 Impact of Temperature on I-V Characteristic of a Solar Panel

Temperature affects the saturation current of solar cell and small affect on I_{PH} so V_{OC} has negative (-) temperature coefficient (for silicon –2.3mV/°C), figure 2.11showing the I-V curve for different temperature variation.

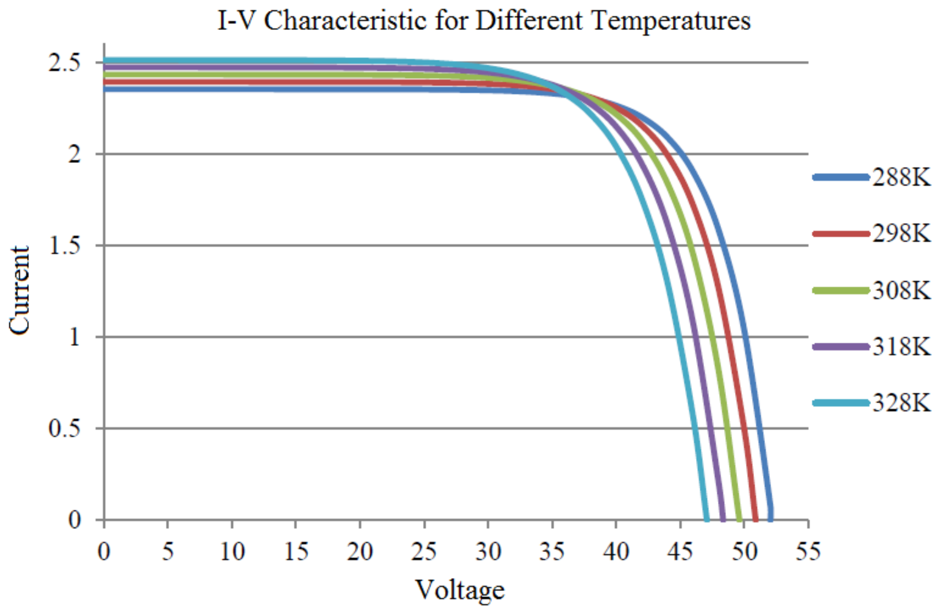


Fig. 2.11 I-V curve for Different Temperatures

2.2 Modeling of Solar Panel in Proteus

In this project "Vikram Solar ELDORA 40-P" solar panel is used as a DC source. From the help of its datasheet its characteristic is achieved by designing on Proteus software as shown in figure 2.12 some data of that panel from its datasheet is given in table 2.1

Pmax	37W
No. of Solar Cells	36
Vmax (V)	18.1V
Impp (A)	2.1A
Open Circuit Voltage	21.77V
Short Circuit Current	2.26A

Table 2.1 Vikram Solar ELDORA 40-P Data

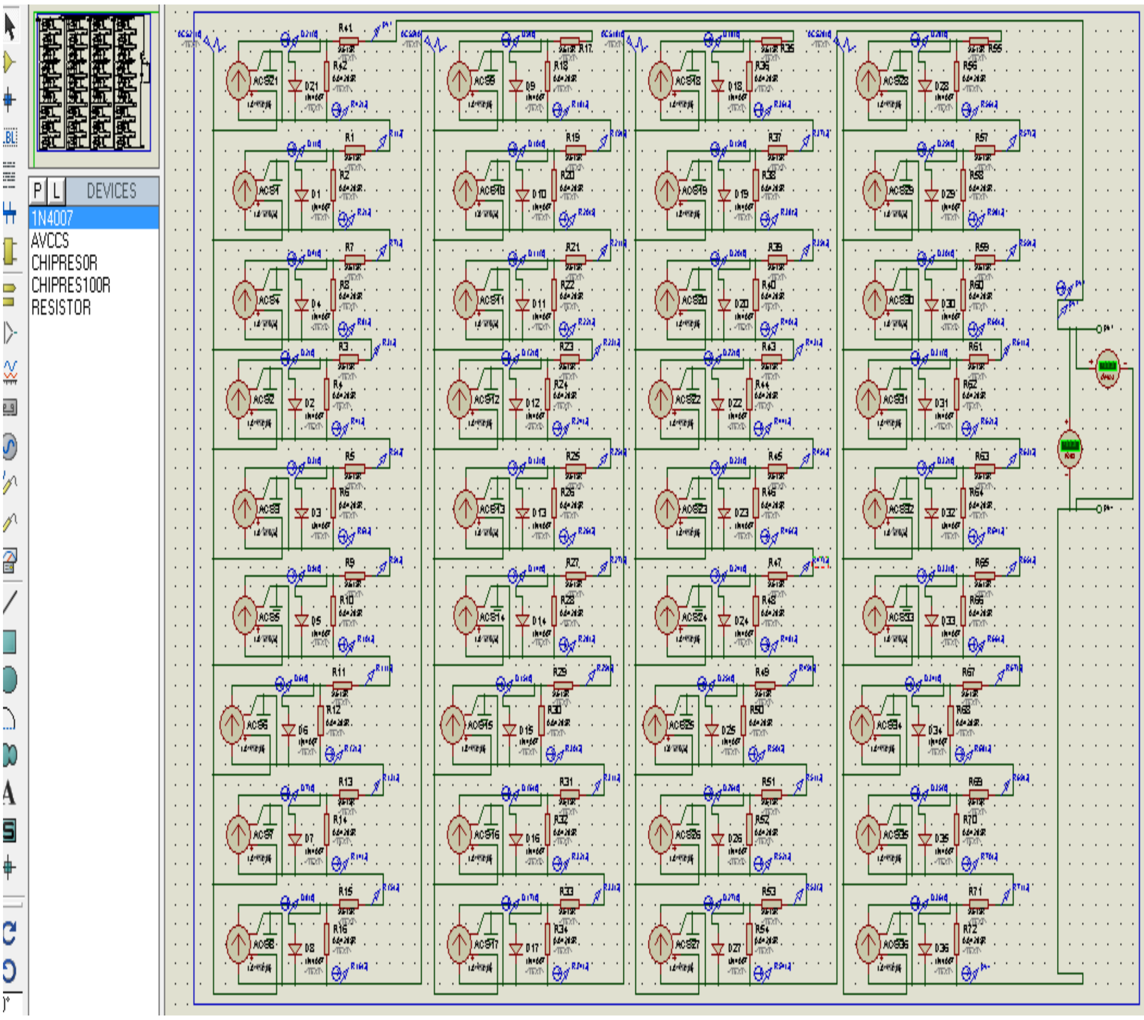


Fig. 2.12 Solar Panel Design on Proteus

In figure 2.12 36 solar cells are connected in series to achieve the ELDORA 40-P panel characteristic. Proteus design solar panel open circuit voltage (21.667V) and short circuit current (2.26A) values are shown in figure 12.13 and 12.14.

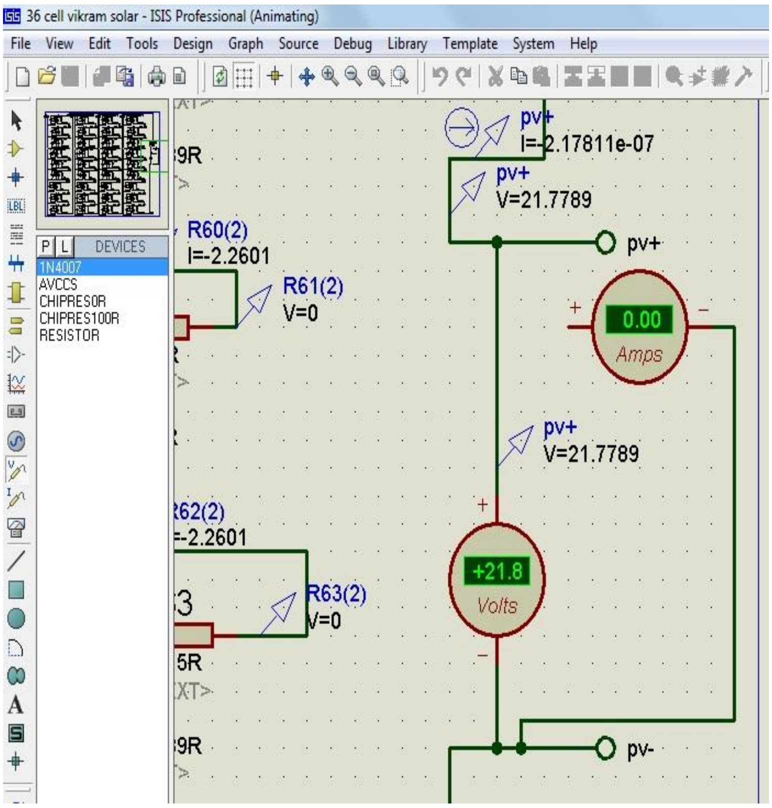


Fig. 12.13 Open circuit voltage

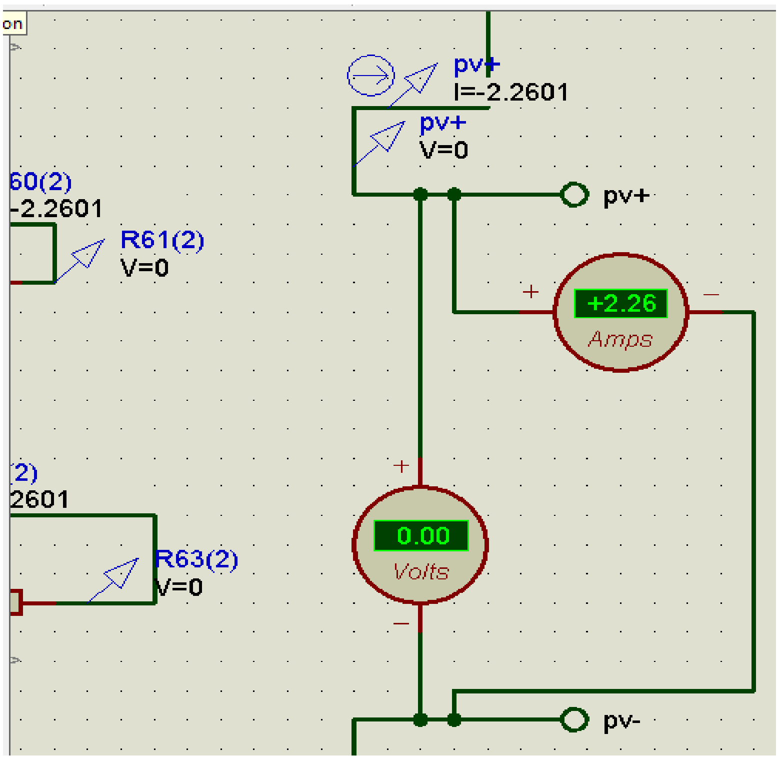


Fig. 12.14 Short circuit current

Chapter 3

Boost Converter for Proposed System

3.1 Overview on DC/DC converter

3.2 Need of DC/DC converter

3.3 Boost Converter

3.4 Design of Boost Converter on Proteus

3.5 Hardware Implementation of Boost Converter.

3.1 Overview on DC/DC converter

The basic DC/DC converter comprises a switch, a filter circuit and load. The DC/DC converter may classify by various methods, one of the basic methods is isolation, according to that it is classified into two types.

1) Isolated DC/DC converter.

2) Non-Isolated DC/DC converter.

In isolated DC/DC converter type the output and input are electrically isolated by the use of a transformer. It is bulky, requires more space and costly while comparing with the non-isolated type DC/DC converter.

The non-isolated DC/DC converters can be further differentiated by element connections like Buck converter, Boost converter, Buck-Boost converter, Cuk converter and Sepic converter.

DC/DC converter is widely used for the purpose of converting unregulated DC input into a regulated DC output [8]. A DC-DC converter is a hart of MPPT hardware implementation. MPPT uses the one of the above converter for regulating the solar input voltage to the MPP and providing impedance matching for the maximum power transfer to the load.

Buck and Boost converter are the basic and simple, easy circuit and less components requires. In this project Boost converter is selected due to [10] –

- It is a step up DC/DC converter, it boosting the input voltage and gives that voltage to the output.
- Boost converter operates by temporarily storing the input energy and then releasing that energy to the output at a higher level of voltage.
- In case if switching device is fail then load is still connected to the source.

3.2 Need of DC/DC converter

A dc/dc converter is an integral part of any MPPT circuit system. Without dc/dc converter no any MPPT circuit can be designed.

When a direct connection is carried out between the source and the load, the output of the PV module is irregularly shifted away from the maximum power point. It is necessary to overcome this problem by adding an adaptation circuit between the source and the load. [11]. A MPPT controller circuit with a DC-DC converter circuit is used as an adaptive circuit.

For maximum power transfer from source to load an extra circuit is required to support the load to match the impedance with source impedance.

3.3 Boost Converter

In a boost converter or regulator output voltage of the converter is greater than input voltage of the converter circuit that means it boosting the input voltage that's way its name is "BOOST" regulator.

The boost circuit consist a energy storing element inductor, a capacitor, a diode, a load and a switching device like Mosfet BJT etc. Circuit diagram of boost converter is shown in figure 3.1 below.

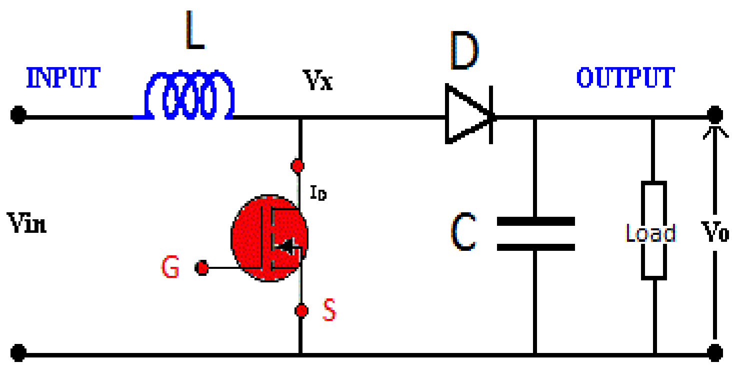


Fig. 3.1 Boost Converter

The control strategy is based on manipulation the duty cycle of the Mosfet causes the voltage change in Boost converter.

Boost Converter Operating Modes

Boost converter have two operating modes based on "ON" and "OFF" condition of switching device (Mosfet) [9]

Mode 1 when mosfet is "ON"

Mode 2 when mosfet is "OFF"

Mode 1

This mode is also known as charging mode. In this mode when mosfet is on inductor is energized and start storing the energy from source during on time (t_1) of mosfet. This time period diode restricts the current flow through it from the source to the load and capacitor is discharging by the load R.

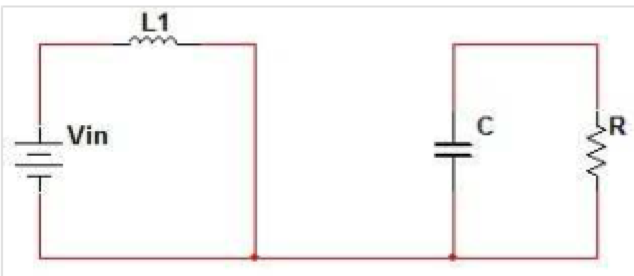


Fig. 3.2 Equivalent Circuit for Mode 1

Assuming the inductor current is linearly rises between i_1 to i_2 then

$$V_{in} = L\frac{i_2 - i_1}{t_1} \tag{3.1}$$

$$t_1 = L\frac{i_2 - i_1}{V_{in}} \tag{3.2}$$

Mode 2

This mode is known as discharging mode. In this mode mosfet is “OFF” and diode is forward bias due to nature of inductor opposing its causing in this mode inductor support source voltage. So the circuit become

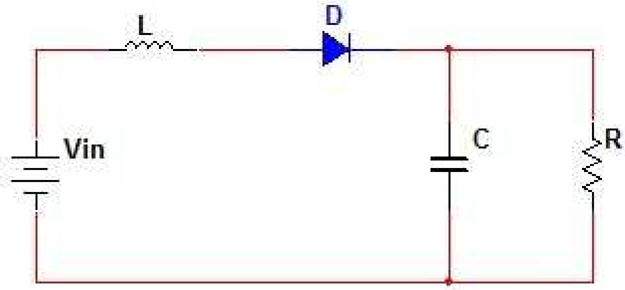


Fig. 3.3 mode 2 equivalent circuit

$$V_L = Vin - Vo \tag{3.3}$$

$$L\frac{i_2 - i_1}{t_2} = Vin - Vo \tag{3.4}$$

$$t_2 = L\frac{i_2 - i_1}{V_{in} - Vo} \tag{3.5}$$

From equation 3.5 and 3.2

$$L(i_2 - i_1) = (V_{in} - Vo\,)t_2 = V_{in}t_1 \tag{3.6}$$

$$T = t_1 + t_2 \tag{3.7}$$

From equation 3.6 and 3.7

$$Vo = \frac{1}{1-\mathrm{D}}Vin \tag{3.8}$$

Where, D = t_1/T

3.4 Design of Boost Converter on Proteus

Proteus design of Boost converter is shown in figure 3.4 and also corresponding component values are also showing.

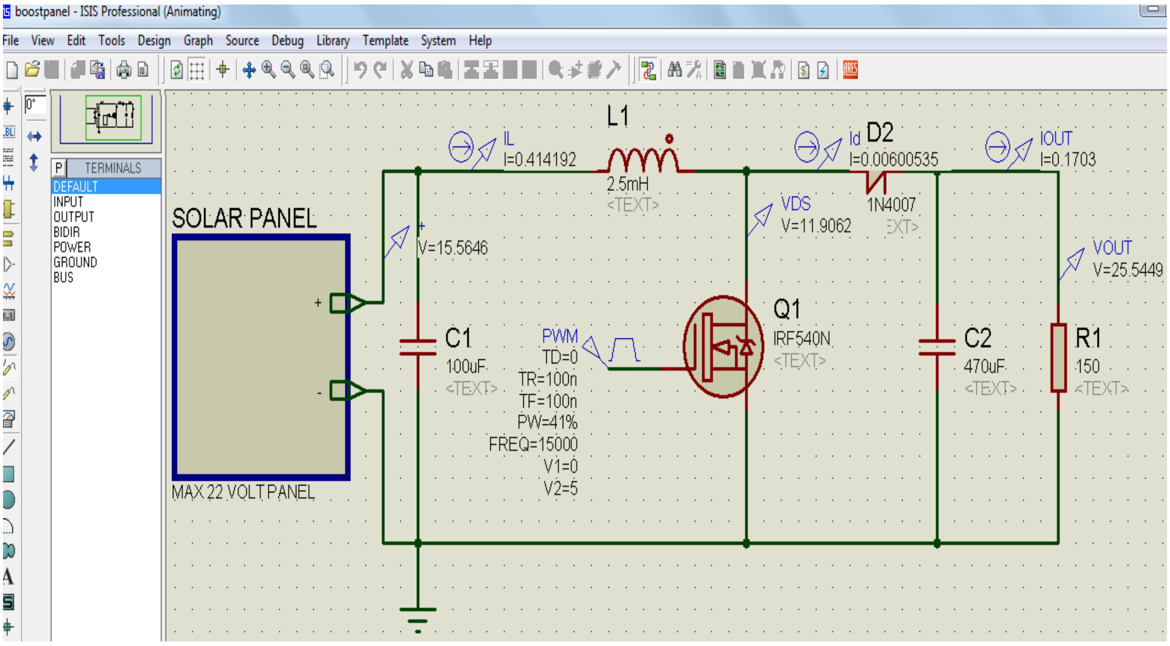


Fig. 3.4 Boost Design on Proteus.

3.5 Hardware Implementation of Boost Converter

According to Boost design on Proteus, Boost converter is implemented by taking corresponding values of its elements. Figure 3.5 shows the photo of hardware of boost converter.

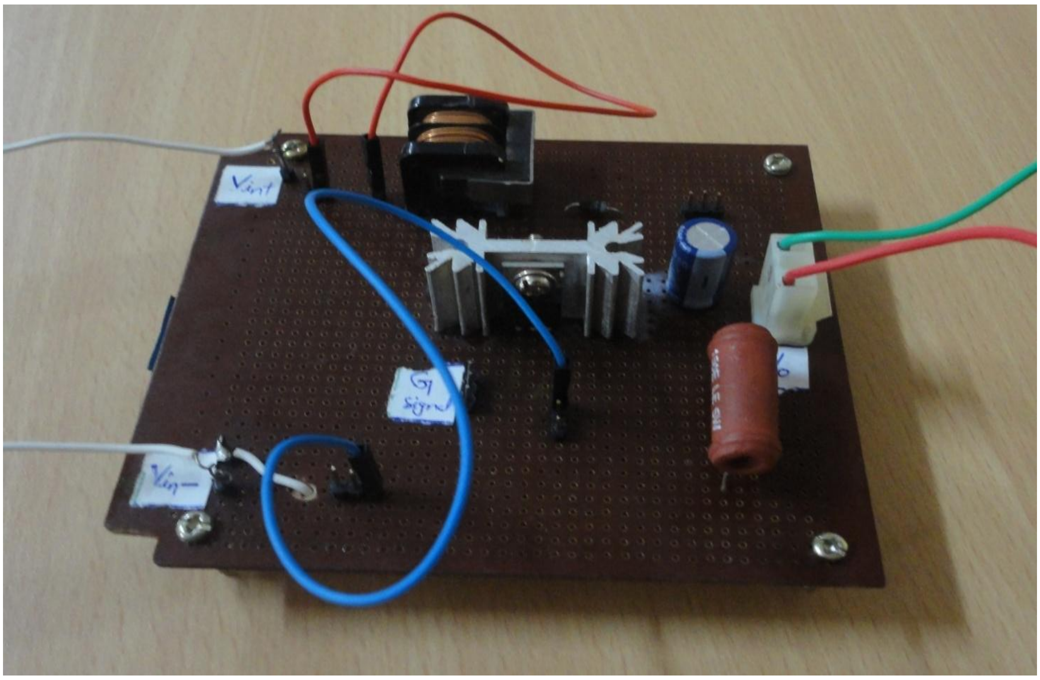


Fig. 3.5 Boost circuit

Table 3.1 contents of the Boost converter circuit inductor and capacitor with a load elements values.

L	2.5 mH
C	470 µF
RLoad	150 Ω

Table 3.1 Boost Elements

The different output voltages at different duty cycle of that Boost converter hardware circuit are shown below

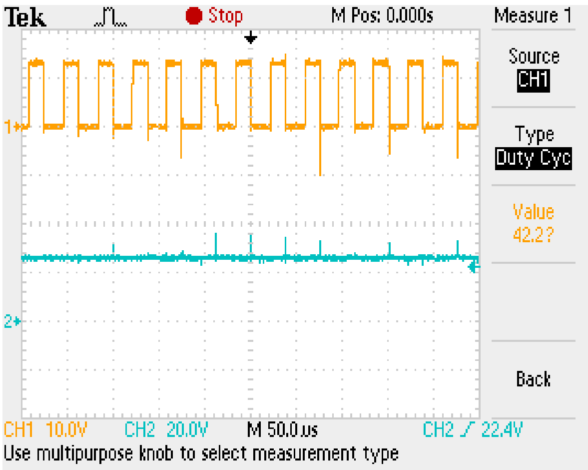


Fig 3.6 Boost O/P at 42.2 % Duty Cycle

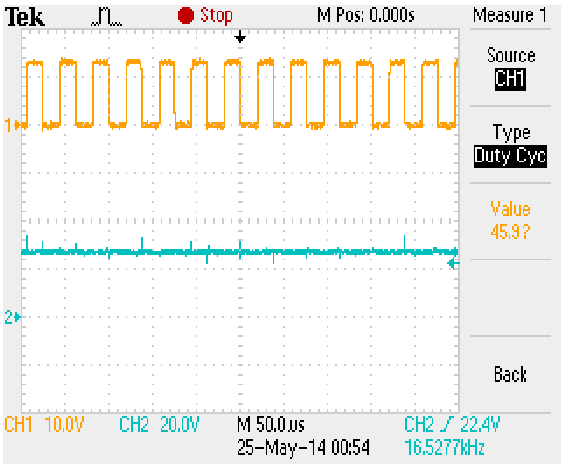


Fig 3.7 Boost O/P at 45.9 % Duty Cycle

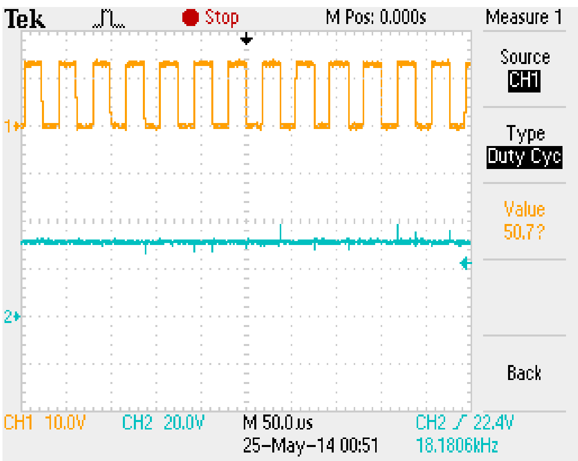


Fig 3.8 Boost O/P at 50.7 % Duty Cycle

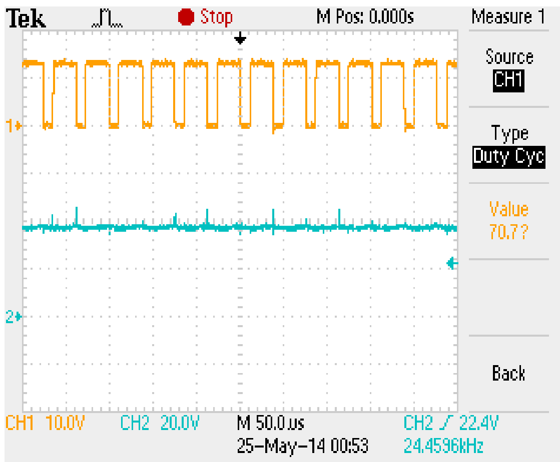


Fig 3.9 Boost O/P at 70.7 % Duty Cycle

In figure 3.6 to 3.9 all boost converter results are summarise in a table form shown in table 3.2

Figure No.	Vi (Volt)	D (%)	Vo (Volt)
Fig. 3.3	15.6	42.2	24
Fig. 3.4	15.6	45.9	25
Fig. 3.5	15.6	50.7	30
Fig. 3.6	15.6	7.7	36

Table 3.2 Boost Converter Operating points

Chapter 4

MPPT Implementation for Proposed System

4.1 Introduction to MPPT

The efficiency of a solar cell is very low and also when solar cells are connected together to form a panel then its efficiency is still not increased [8]. In order to increase the efficiency (η) of solar cell or solar panel we have to use maximum power transfer theorem. The maximum power transfer theorem says that the maximum power is transfer when the output resistance of source matches with the load resistance [12] i.e. solar cell or solar panel impedance. So all MPPT technique's principles are based on maximum power transfer theorem that always trying to matching the impedance of load to source.

The effectiveness of MPPT is given by following equation. [17]

$$\eta_{MPPT} = \frac{\int_0^t \mathrm{P}_{\mathrm{measured}}(\mathrm{t})\mathrm{dt}}{\int_0^t P_{actual}(t)dt} \tag{4.1}$$

The maximum power point tracking (MPPT) is now habitual in grid-connected PV power generation system and it is becoming more popular in isolated or stand-alone power generation systems as well because of the V-I characteristics in PV power generation systems is nonlinear, So it is difficult to supply a constant power to a certain load.

There is confusion with MPPT that many people think that it is a mechanical device that tracking the sun, it rotates the solar panel or solar cells as well as tilts it in the direction of sun where the solar irradiance is more.

But the MPPT is an electronic device that extracts maximum possible power from solar panel. It varies the electrical operating point of the panel by changing the DC/DC converter duty cycle to matching the load impedance with PV cells impedance. Mechanical tracking system can be used with MPPT, but these two systems are completely different from each other.

To understand how the MPPT works, let's first consider a solar panel. A solar panel generates power by using the photovoltaic effect then obvious a solar panel has a P-V characteristic that means for a different operating point of the solar panel, a different power output can be achieved. Therefore the maximum possible power is obtain from the solar panel when it operates at only for one specific operating point of the P-V characteristic of solar panel. This point in the P-V characteristic is called the Maximum Power Point (MPP). This MPP changes when the solar irradiation changes or temperature changes or when the solar panel is partially shaded [13]. So when these three factor changes, the solar panel operating point is also changes. To track that constantly changing MPP a device is needed called Maximum Power Point Tracker (MPPT).

4.2 MPPT Requirements

For implementation of MPPT the following things are required [14, 18].

- Sensors.
- Analog to Digital converter.
- Microcontroller.
- A MPPT algorithm to run the microcontroller.
- PWM output generator.
- A DC-DC Converter.

4.2.1 Sensors

For MPPT many types of sensors are required like current sensor, voltage sensor, temperature sensor, pyranometer etc. But for this project as already information is shared in chapter 1 that only two sensors is required i.e. current sensor and voltage sensor for P and O algorithm implementation.

4.2.1.1 Voltage Sensor

In this project for P and O MPPT implementation solar panel terminal voltage is required to measure. We can use Hall Effect base voltage sensor but for coast effective implementation a very simple voltage sensor based on very simple concept voltage division theorem is used.

For this kind of voltage sensor two series connected resistors (R_1 and R_2) should connect across solar panel terminal and a wire is coming out from midpoint of these two resistor, that wire is given to the ADC for microcontroller reading.

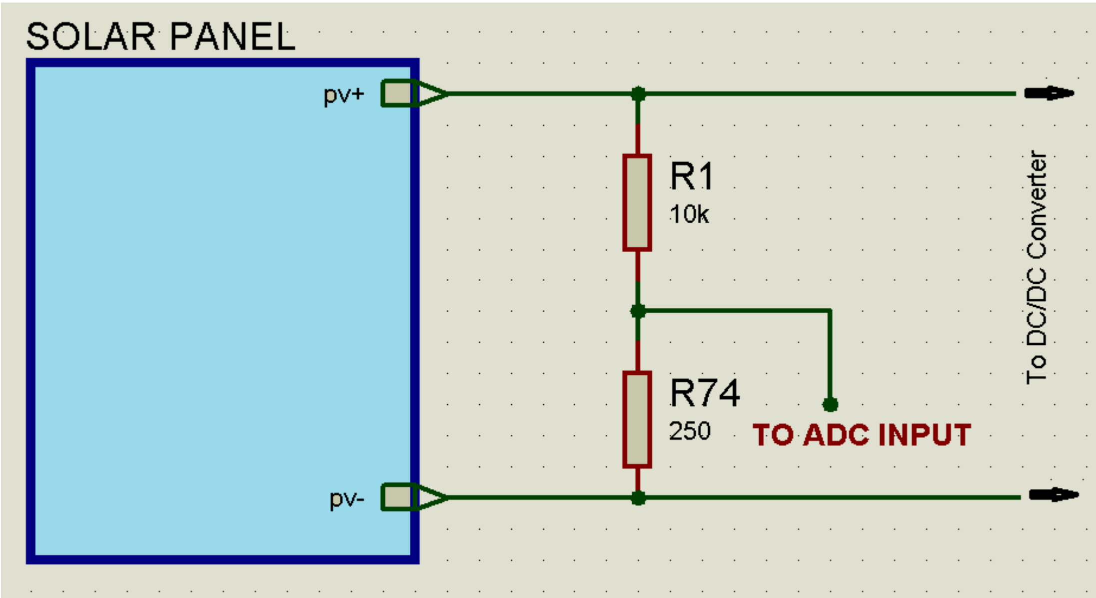


Fig. 4.1 Voltage Sensor

One thing is important R_1 should be greater than R_2 that proportionally decrease the panel voltage and make it allowable to read by microcontroller. Suppose solar panel rated voltage is 25 Volt and microcontroller have maximum allowable voltage is 5 Volt then for 25 Volt voltage sensor have proportionally down the voltage to 5 Volt by choosing the value of $R_2 = 250\Omega$ and $R_1 = 1000\Omega$ that is $R_2 = 25\ \%$ of R_1. This combination consumed very less energy (i.e. in few mW).

4.2.1.2 Current Sensor

For P and O MPPT implementation we need to measure the solar panel output current for that in this project a Hall Effect based ACS712 current sensor (made by Allegro Micro Systems) is used.

Fig. 4.2 ACS712 Current Sensor Ref-www.google.com/image

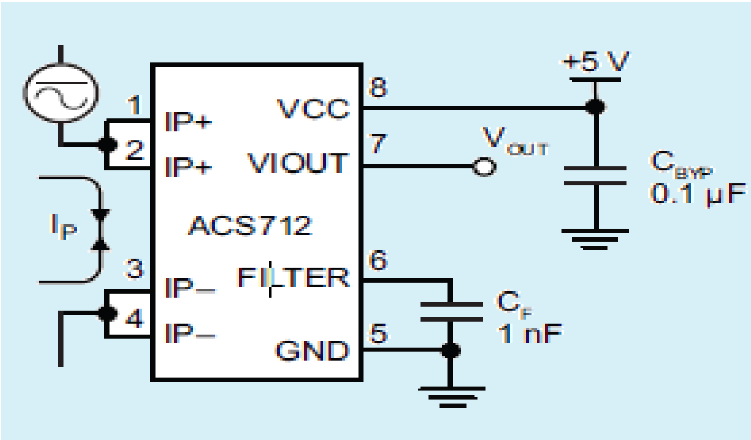


Fig. 4.3 Pin Diagram

Features of ACS712 current sensor

- It is a fully integrated Hall Effect based linear current sensor.
- AC and DC both current sensing capability.
- Very cheap and compact size.
- 5 V supply Voltage.
- Sensitivity is 66 to 185 mV/A.
- Bandwidth is 50 kHz.

4.2.2 Analog to Digital converter

The Analog to Digital Converter has a task is to measure the input signals that is in between minimum 0 to maximum 5 V range that represent the solar panel terminal output current and voltage. Analog to Digital Converter convert that input signal into binary numbers and send that digital numbers to the microcontroller. these measurement and conversion perform by ADC should be accurate as possible as for that it is better to use a development board kit in which ADC circuit is already built or use complete development board kit on that both ADC and microcontroller interface circuit and other important circuit is built already. One another thing is that two ADC is required to measure two different quantities i.e. solar panel voltage and current.

4.2.3 Microcontroller

Microcontroller is the main brain of the MPPT that decide the duty cycle of DC/DC converter on the basis of measuring digital input of panel terminal voltage and current. For doing that job we need microcontroller have some features that it should have more than 1MHz clock frequency, available in DIP packages, 8 ADCs with 8 bits register length and PWM signal generation is possible with resolution of 16 bits.

For best of use in this project Arduino complete development board kit is used [15], it has on chip ADC and PWM generator.

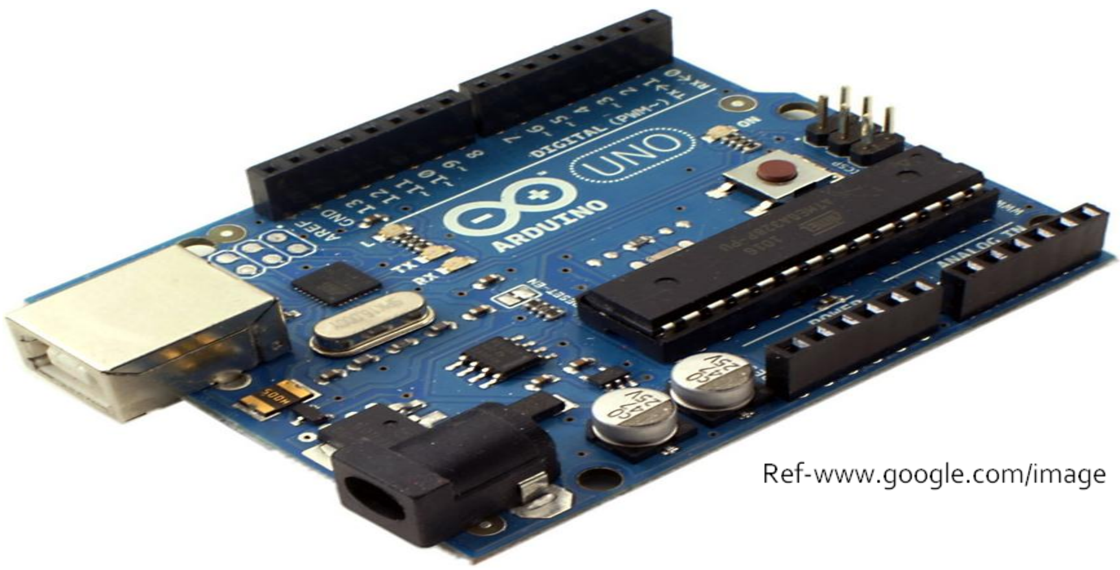


Fig. 4.4 Arduino Development Board

4.2.4 A MPPT algorithm to run the microcontroller

In PV power generation system MPPT performs a very important role that it extracts maximum possible power from panel by varying the duty cycle of

DC/DC converter and that duty cycle is controlled by different MPPT techniques and its algorithms. Some are listed below.

- Open Circuit Voltage.
- Short Circuit Current.
- Constant Voltage.
- Perturb and Observe.
- Incremental Conductance
- Temperature Method.
- Intelligence MPPT Techniques.
    1. Fuzzy Logic Based.
    2. Artificial Neural Network Based.

These techniques are categorists by its features [16] like Simplicity, Types of control strategies, Number of Control Variables, Types of Circuitry (digital or analogical implementation), convergence speed, Number of sensors required, Cost effective etc.

In this project very famous Perturb and Observe is chosen by considering the above features of MPPT techniques specially simplicity, number of sensors required and cost effective.

Perturb and Observe

The Perturb and Observe (P&O) technique is also known as "Hill Climbing" method. It is most popular and commonly used [17]. The faction of basic form of P and O algorithm is as follows. In figure 4.5 a PV panel's output power curve as a function of voltage (P-V characteristics) is shown in figure 4.5.

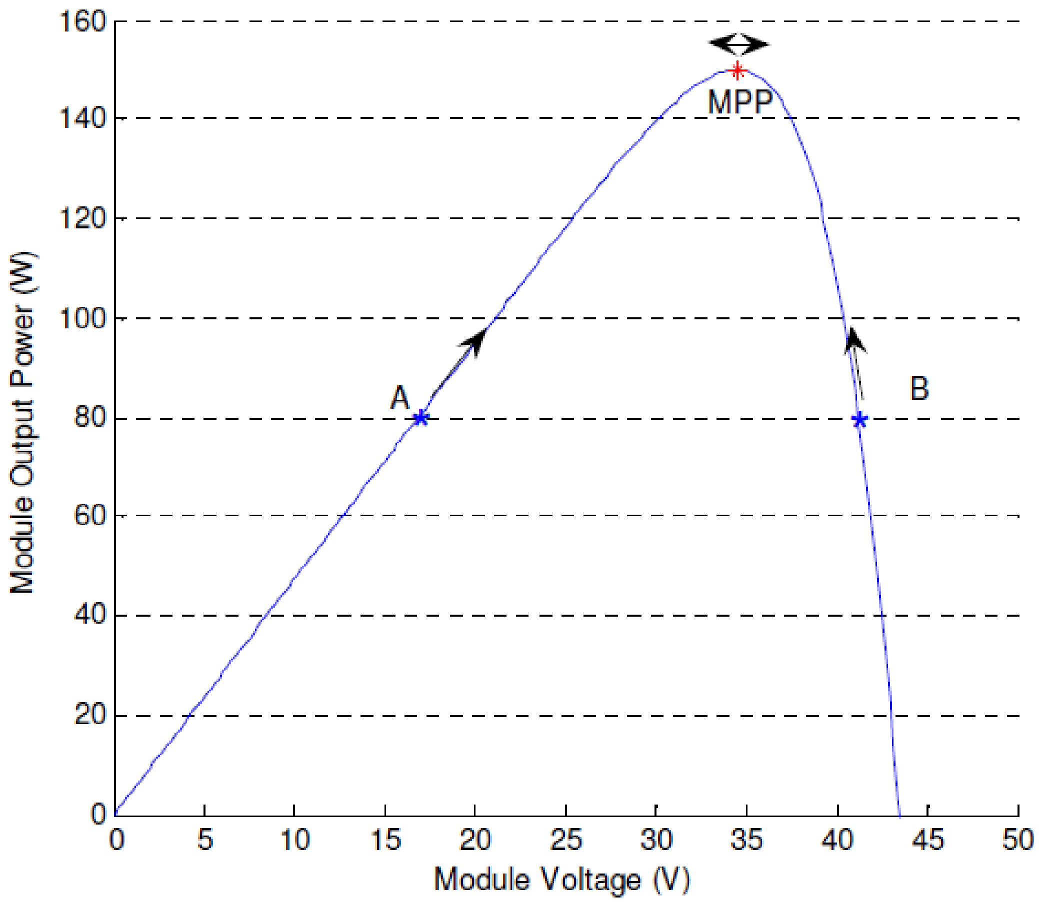


Fig. 4.5 Power vs. Voltage Curve of Panel [Ref Datasheet BP SX 150 S PV module $(1\text{KW}/m^2, 25^oC)$]

At a constant irradiance and constant temperature on PV panel assuming the PV panel is operating at a point which is away from the maximum power point. In this algorithm first PV panel terminal voltage and current are measured and corresponding power P(k-1) is calculated after that small increment on operating voltage or in duty cycle of the dc/dc converter in one direction is perturbed and hence the corresponding power P(k) is calculated. By comparing P(k-1) and P(k), ΔP is calculated. If ΔP is positive then the perturbation is directed in the correct direction and it is moving the operating point nearer to the MPP. Then further voltage perturbations or i.e. duty cycle perturbations in the same direction will move the operating point toward the MPP; if ΔP is negative then perturbation direction should be reversed. In this way the maximum power point is recognized [18, 19, 20]. The flow chart of P and O is shown in figure 4.6.

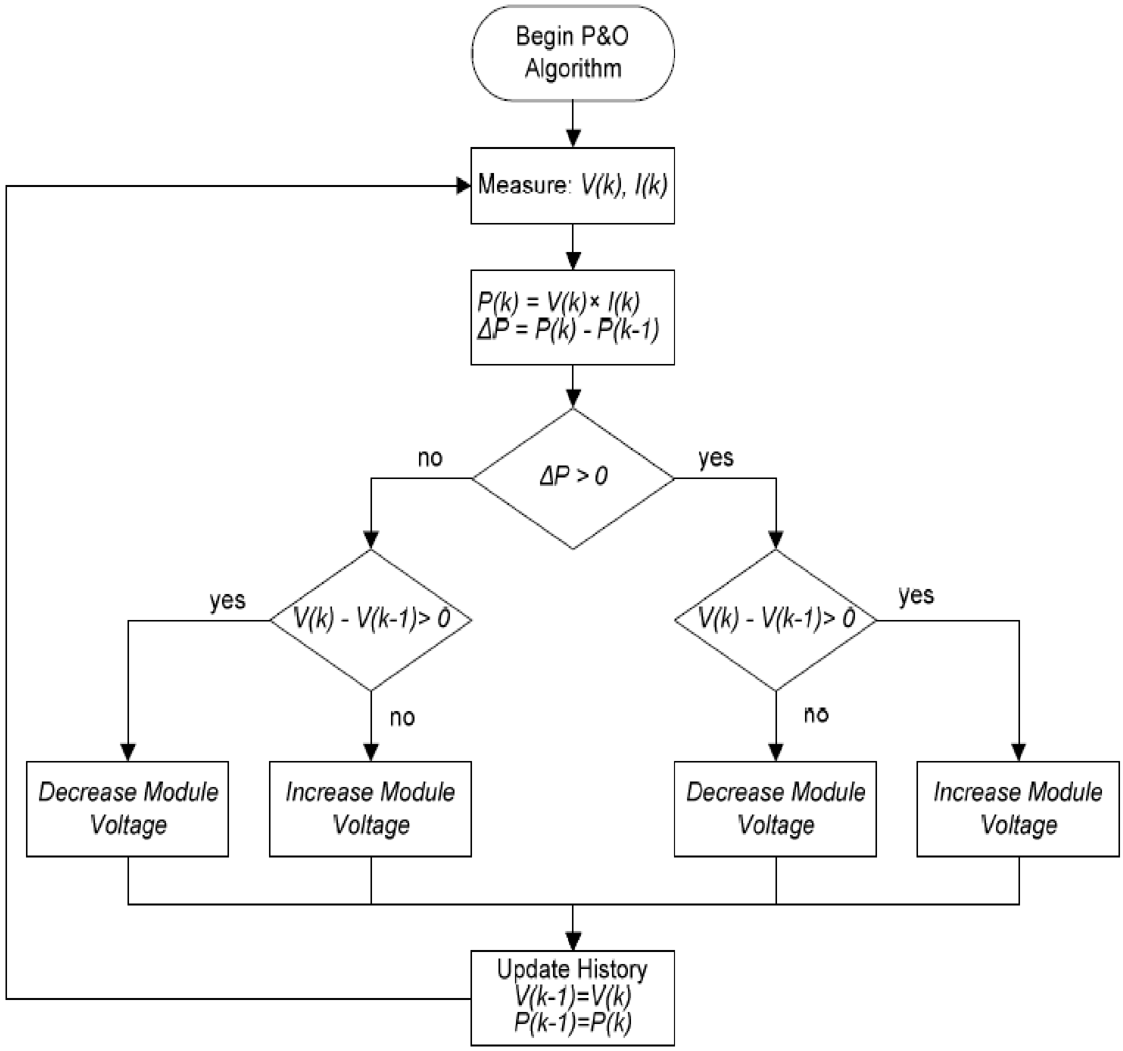


Fig. 4.6 P & O Flow Chart [18, 19]

4.2.5 PWM output generator

We need 16 bits resolution PWM signal output to switching the mosfet of DC/DC converter. In Arduino development board microcontroller have on-chip PWM signal generator. So no need to take more care about that for implementation just we have to write a program for that.

4.2.6 A Dc-Dc Converter

The DC/DC converter is widely used in MPPT circuit for the main purpose of matching the load impedance with the panel impedance by changing its operating duty cycle. A DC-DC converter converting a regulated DC output voltage from an unregulated DC input voltage [9]. A DC-DC converter is a hart of MPPT hardware implementation.

MPPT technology uses that DC-DC converter for regulating the solar input voltage and reach to the peak voltage i.e. MPP and provides impedance matching from source to load for the maximum power transfer to the load. DC-DC converter is already discussed in chapter 3.

4.3 Design of MPPT Circuit on Proteus

In this project Proteus Software is chosen for implementation. Figure 4.7 showing the snapshot of MPPT circuit design on Proteus.

In figure 4.7 solar panel terminal is connected to the Boost converter. Solar panel terminal voltage and current is sensing by sensors, in figure looking like op-amp circuit is a current sensor representing ACS712.

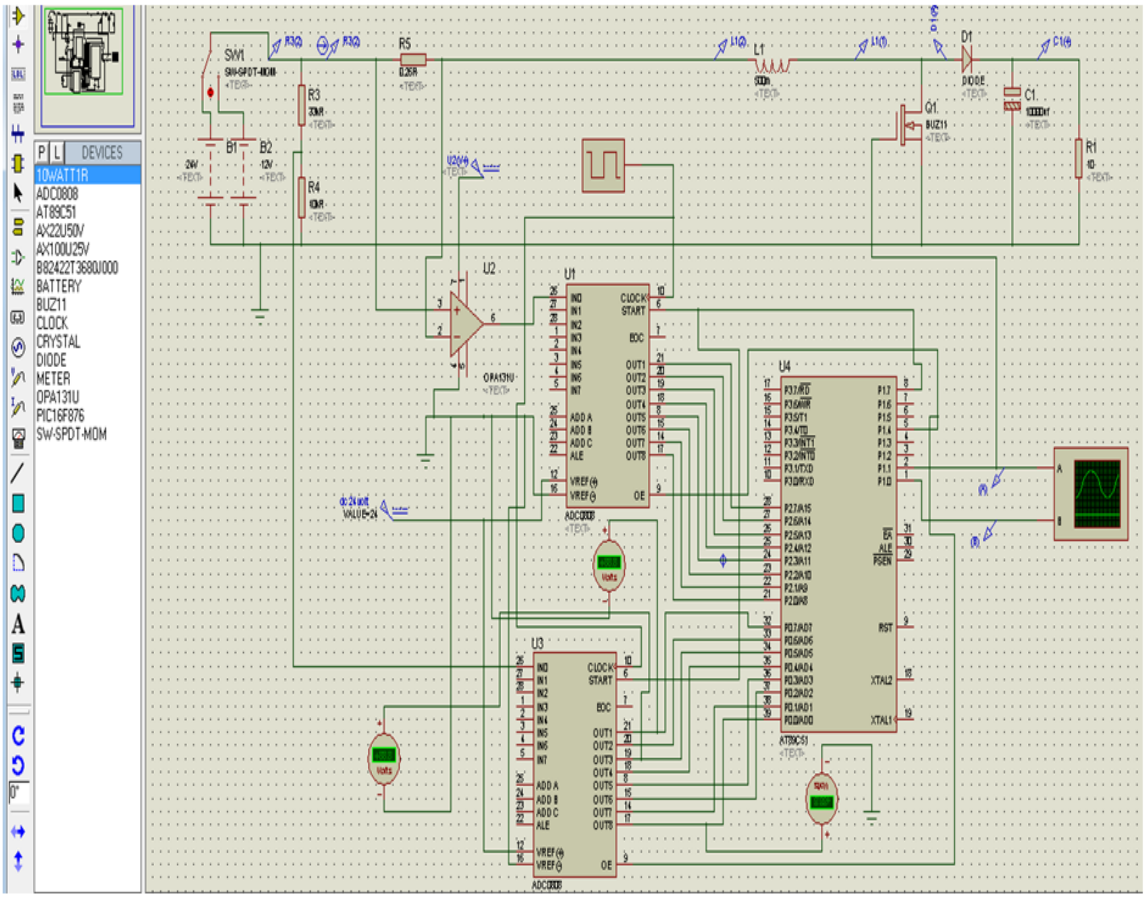


Fig. 4.7 MPPT Circuit Design on Proteus

Two ADC converters are showing interfaced with microcontroller and microcontroller generates PWM signal to switching the mosfet of Boost converter. Generated PWM signal by microcontroller is shown in oscilloscope is shown in figure 4.8

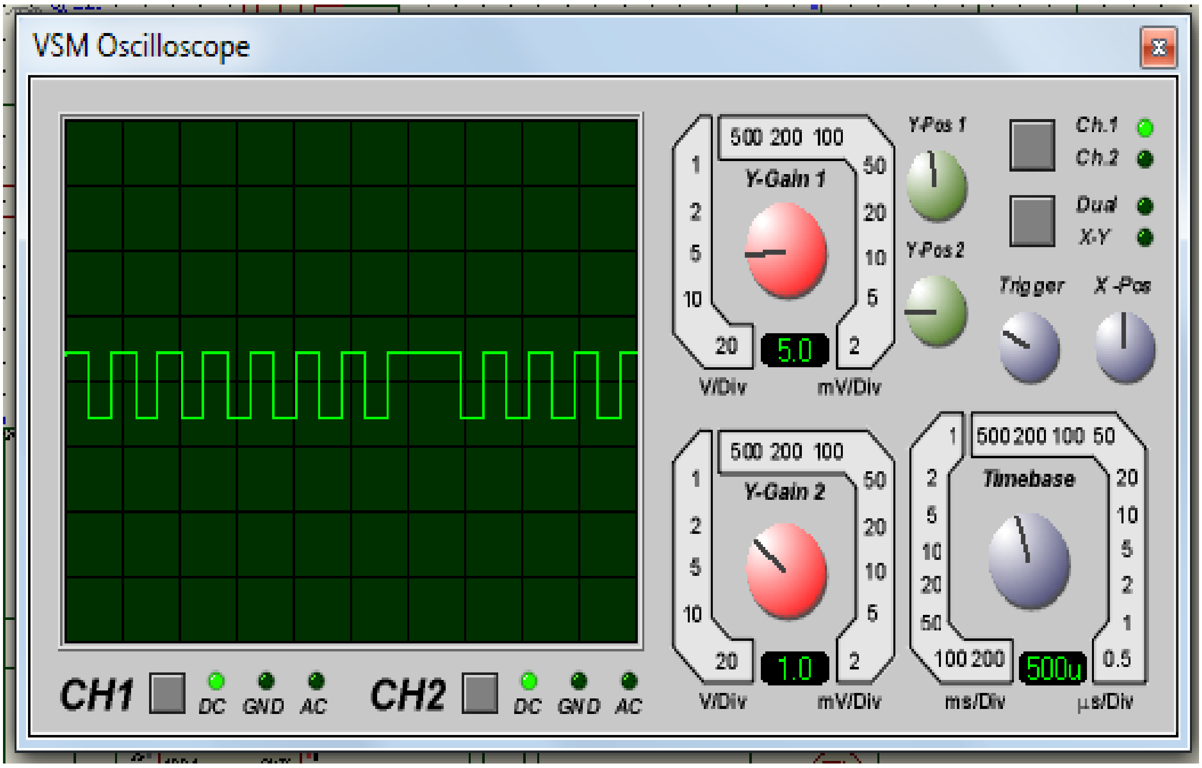


Fig. 4.8 Generated PWM Signal From MPPT Circuit

4.4 MPPT Hardware Implementation

Photo of MPPT hardware circuit is shown in figure 4.9, in which two ADC's, microcontroller and their interfacing connections and PWM generator circuit is completely replaced by Arduino Development Board Kit and its output signal i.e. PWM signal is directly given to the gate terminal of mosfet of Boost converter circuit.

In figure 4.10 panel output voltage and current is showing after MPPT circuit is connected that means ACS712 current sensor, Arduino development board kit, and voltage sensor. After that entire MPPT algorithm runs and panel output voltage is settled to 15.6 Volt which is Vmpp of the panel, so it matches the impedance from source to load and transfer maximum power.

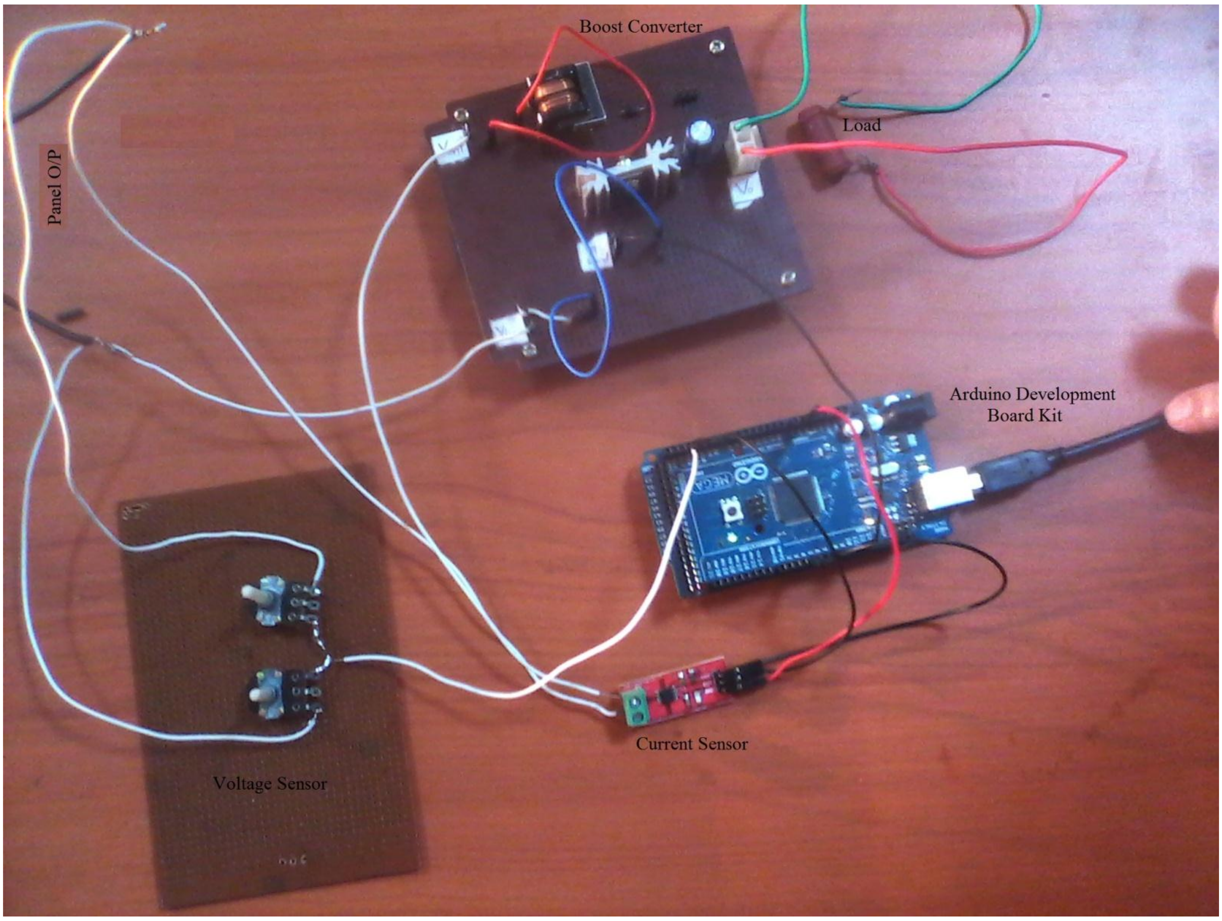


Fig. 4.9 MPPT hardware circuit with sensors

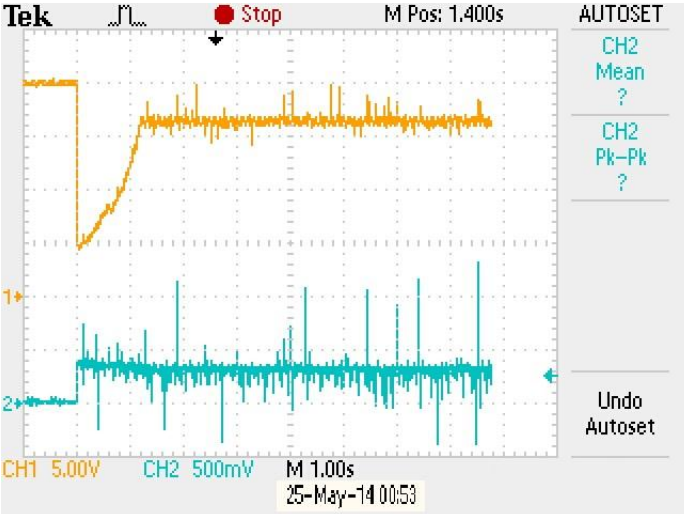


Fig. 4.10 Panel O/P Voltage and Current after Connecting MPPT Circuit

4.5 Summary of Chapter

This chapter describes the necessity of maximum power point tracking and working of Perturb and Observe method. Proposed design of MPPT circuit on Proteus using Perturb and Observe technique has been described. MPPT hardware circuit is implemented with the help of ACS712 current sensor and Arduino complete microcontroller development board kit, which contains Atmega2560 microcontroller that generates PWM signal for switching the MOSFET of DC/DC converter.

Chapter 5

Proposed Battery Charge Controller

5.1 Introduction of Battery Charge Controller

5.2 Proposed Battery Charge controller design on Proteus using 555 Timer IC

5.3 Hardware implementation of Battery Charge Controller

5.4 Difference between Battery charge controller and Solar Charge Controller.

5.1 Introduction of Battery Charge Controller

In stand-alone photovoltaic power generation system, to store the electrical energy produced by the solar PV Array a electrical storage battery is required due to demand of energy does not always coincide with its generation.

To increase the storage capability of battery more than one battery are can be used and these batteries can be connected in any combination of series connection or parallel connection or combination of both series and parallel connections as shown in figures below.

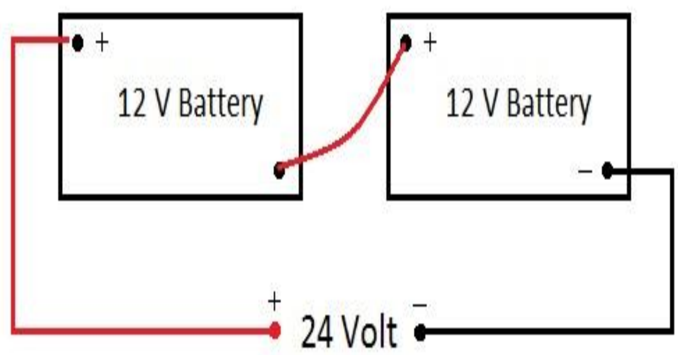


Fig. 5.1 Series Connection

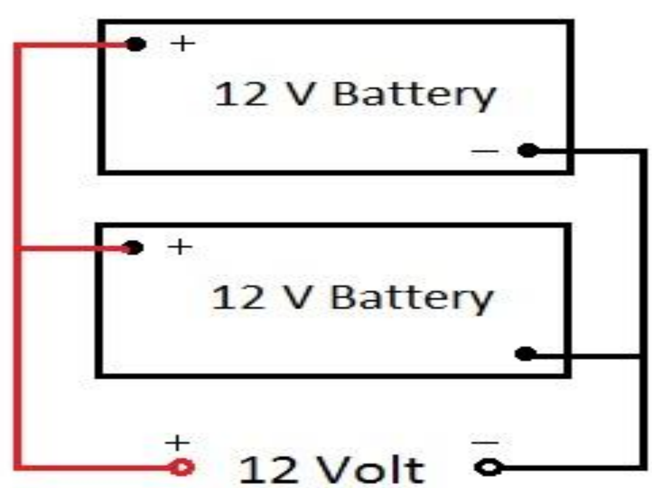


Fig. 5.2 Parallel Connection

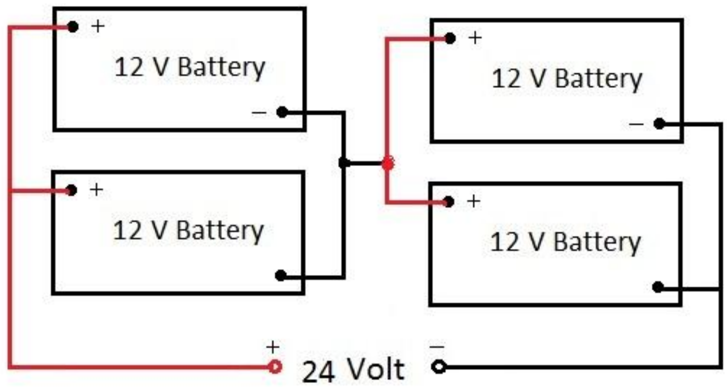


Fig. 5.3 Parallel-Series Connection

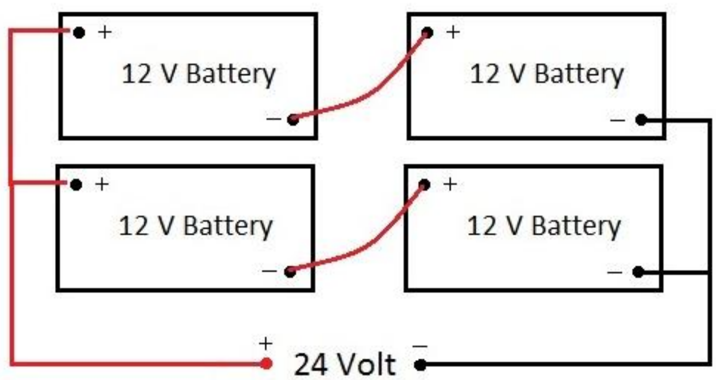


Fig. 5.4 Series- Parallel Connection

In figure 5.1 two 12 Volt batteries are connected in series and built together a single source of 24 Volt storage element.

In figure 5.2 two batteries (each 12 Volt) are connected in parallel and formed together a single source of 12 Volt storage elements. Here voltage rating is still 12 Volt but current rating of that storage element is increased. In figure 5.3 first two batteries (each 12 Volt) are connected in parallel and then connect in series with another set of two batteries (each 12 Volt) which are individually connected in parallel and formed a single 24 Volt storage element with increasing current ratting.

In figure 5.4 first two sets of batteries (each 12 Volt) are connected first in series and after that connect in parallel combination with another same set of two batteries (each 12 Volt) which are individually connected in series and formed a single 24 Volt storage element with increasing current ratting.

When multiple batteries are used as a one storage element then it is called Battery Bank. Normally the battery storage capability is defined by its voltage rating and Ah (Ampere-Hour) rating. Battery backup time is finding out by following equation.

$$Backup\ Time = \frac{\text{Battery Voltage(V) x Battery Capacity(Ah) x Battery Efficiency}(\eta)}{Load(VA)} \quad (5.1)$$

A storage battery has following primary functions in a PV power generation system.

- To store electrical energy when it is produced by the PV array and to supply energy to electrical loads as needed or on demand.
- To supply power to electrical loads at stable voltages and currents, by suppressing or smoothing out transients that may occur in PV power generation system.
- To supply surge or high peak operating currents to electrical loads.

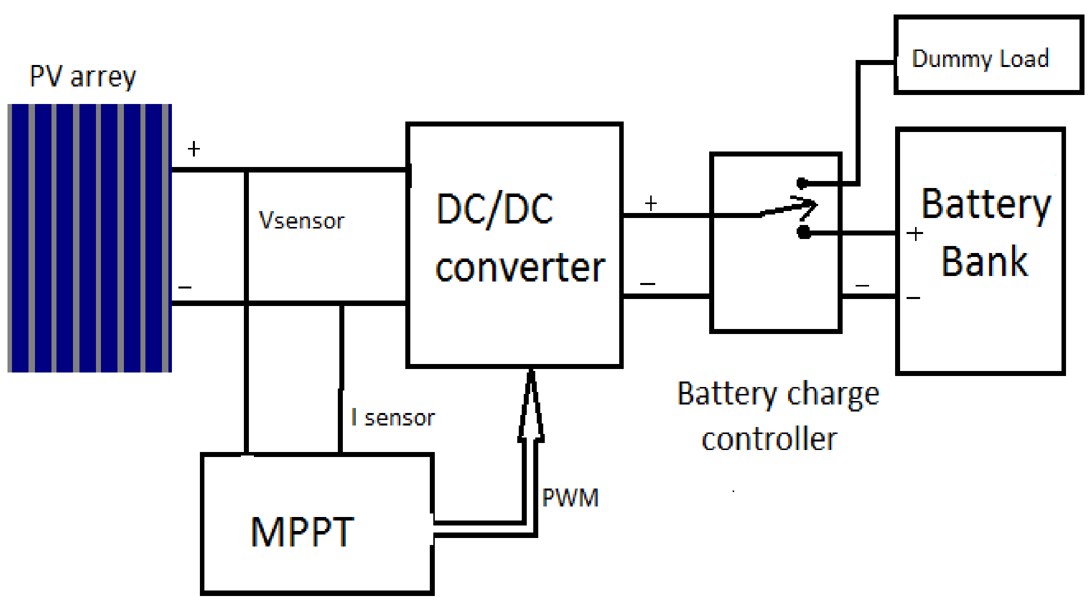


Fig. 5.5 Position of the Battery Charge Controller

A battery has above characteristics and it performing very important role in solar photovoltaic power generation system so it is duty and need to protect the battery. For that we need a Battery Charge Controller.

The first question come in mind is that what is Battery Charge Controller?

"A battery charge controller is a regulator that regulates the amount of charge coming from the panel that flows into the battery bank in order to avoid the batteries overcharging and over discharging by the load".

The position of the battery charge controller is shown in figure 5.5, which is connecting between DC/DC converter and battery bank. The reason for why need of battery charge controller is very clear by its basic functions.

The Battery charge controller has mainly three basic functions:-

1. To limit the voltage from the solar panel and regulate the voltage so as not to overcharge the battery.
2. Not to allow the battery to get into deep discharge mode while DC loads are used.
3. To allow different DC loads to be used and supply appropriate voltage.

5.2 Proposed Battery Charge controller design on Proteus using 555 Timer IC

It is a very new and different technique to control the charging of battery. This technique can be used any where there battery charge controlling is required [21]. The Proteus software is used to implement the battery charge controller shown in fig-5.6 with its connection circuits using 555 Timer IC. Its working is explaining with its hardware implementation.

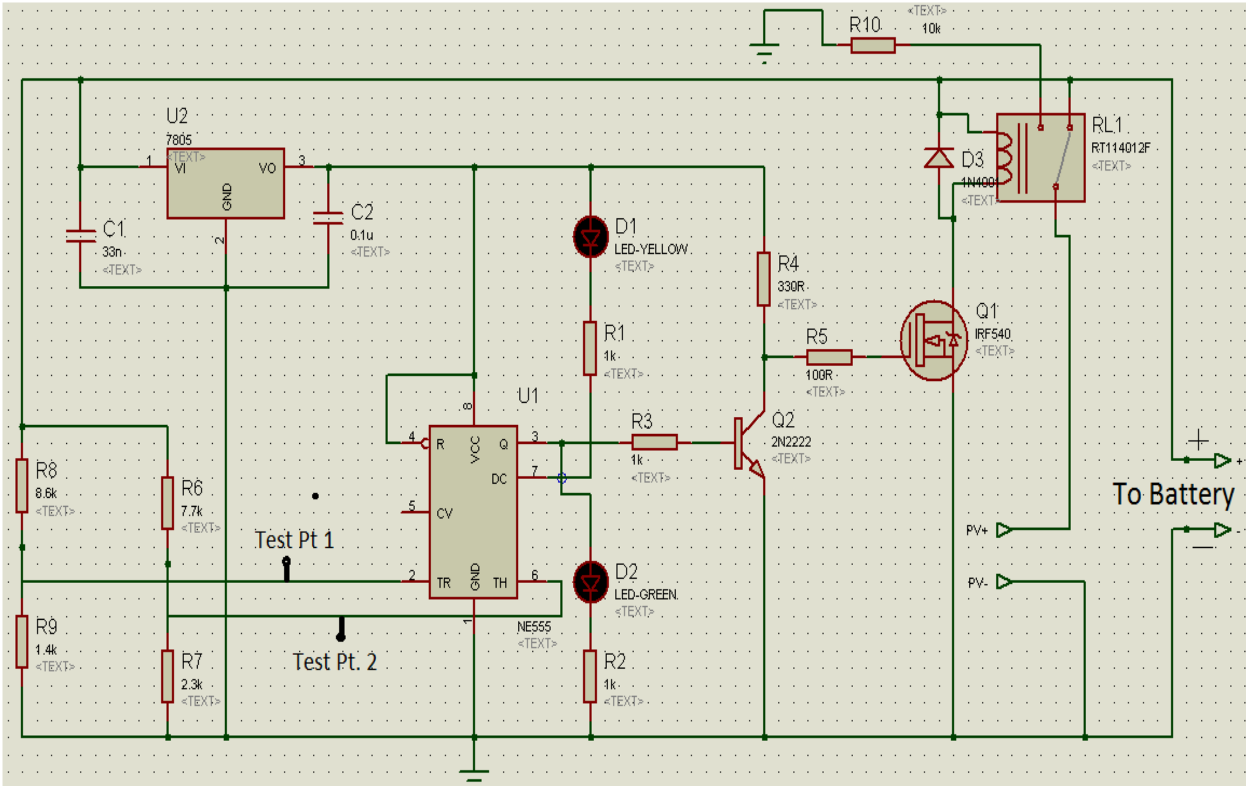


Fig. 5.6 Proteus Design of Battery Charge Controller

Tuning of the Circuit

Tuning of the circuit is required to set the batteries overcharging and over discharging, for that we have to assume 12V Battery bank is using for its charge controlling.

Let first decide battery overcharging point that is battery maximum allowable voltage up to that we can charge it, let considered 14.9 volt for 12 volt battery as according to the datasheets of many 12 Volt batteries. And discharging point that we can decide up to what voltage level battery should discharge and after that it should again start charging for that let assume 11.9 volt here, which is just for keeping the battery charge near to the 12 Volt.

For Discharging point:-

- Attach a variable DC power supply to the battery terminals and set the power supply to 11.9V.
- Measure the voltage at Test Point 1. With adjusting R1 until the voltage at the test point 1 is as close to 1.667V (14% of 11.9V.) [21]

For Overcharging point:-

- Set your variable DC power supply to 14.9V.
- Measure the voltage at Test Point 2. With adjust R2 until the voltage at the test point is as close to 3.333V (23% of 14.9V) [21].

5.3 Hardware implementation of Battery Charge Controller

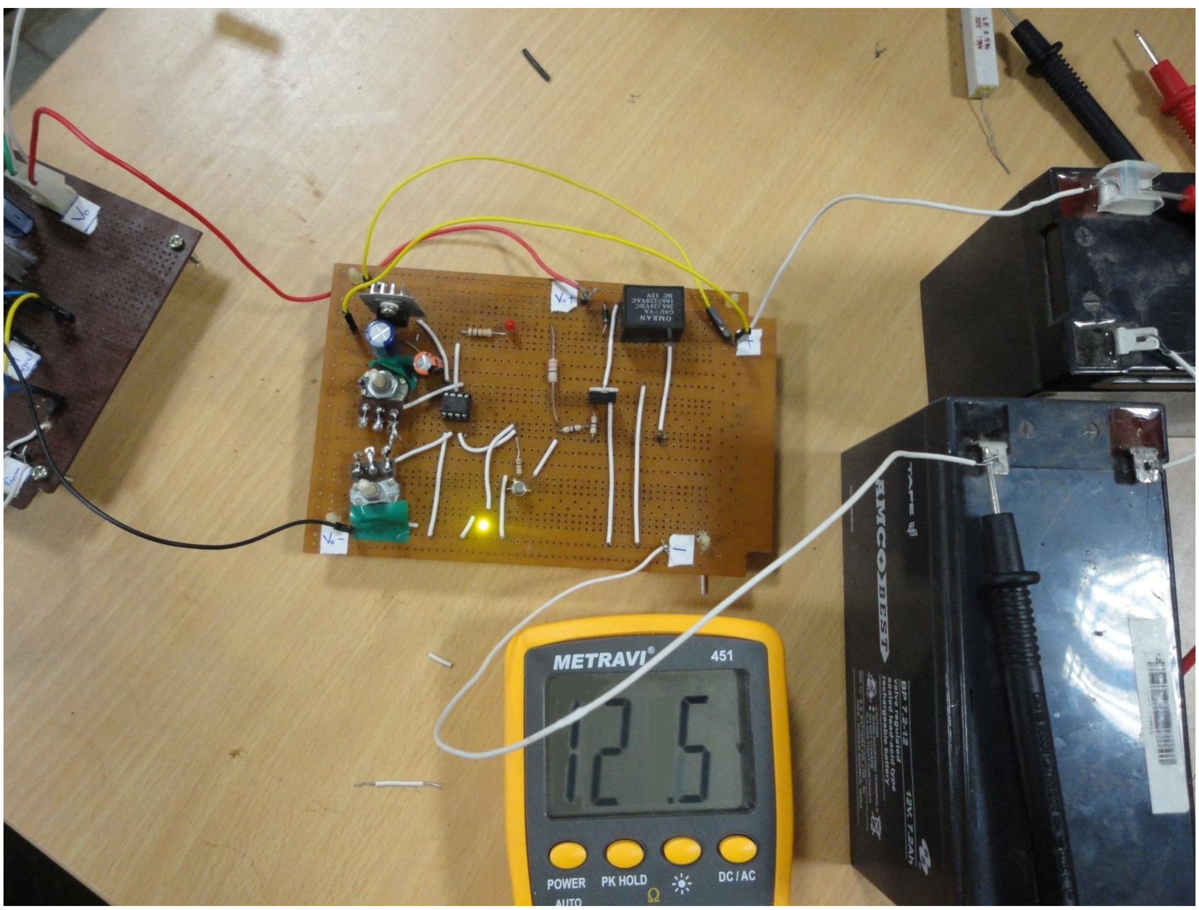


Fig. 5.7 Battery Charge Controller (charging condition)

Proteus design of Battery Charge Controller is implemented on PCB as shown in figure 5.7 connecting between boost converter and battery.

In figure 5.7 looking like a small black box, is a 12V normally closed (NC) relay which the main switch that allows the solar power flow into the battery or into the dummy load. Relay is NC type so normally it makes contact between solar output and battery terminals and when relay operates it supply the power to the dummy load and not allow any power flow to the battery bank. In the operation when green led is ON showing battery is charging and when red led will on that means relay will have been operated to switch the supply from battery to dummy load.

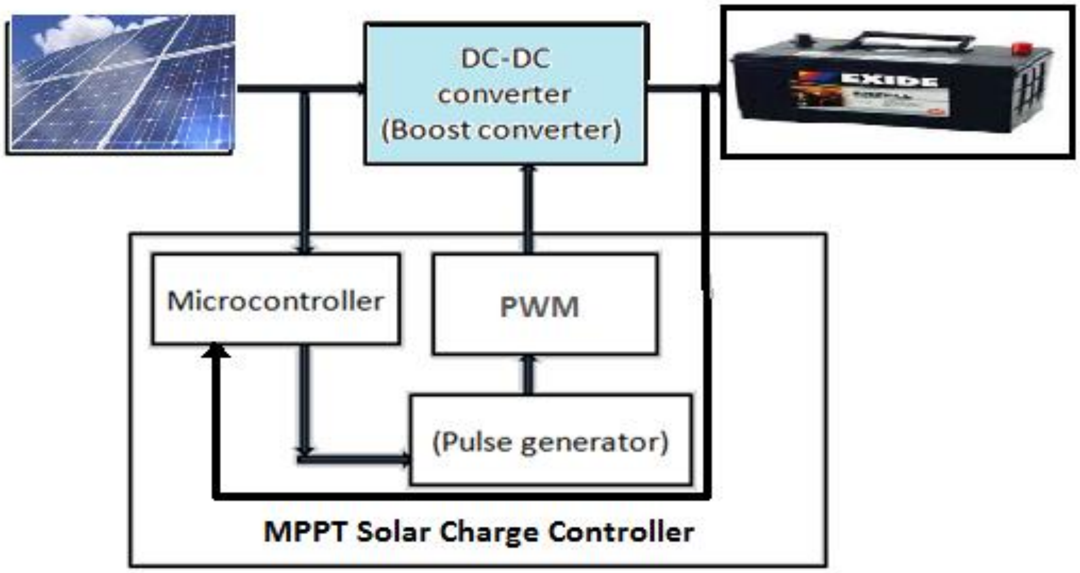
555 Timer IC sense the battery voltage, when battery voltage is matched with the charging and discharging voltage value timer IC produce signal corresponding to its pre-set voltage value and relay will operate according to that and switching the circuit. The two variable resistors connected to the 555 timer IC by varying them we can adjust the voltage level point for battery on that point relay is operative if other voltage rating battery is uses.

5.4 Difference between Battery charge controller and Solar Charge Controller

The connection blog diagram of Solar Charge Controller is shown in figure 5.8. The major difference between Solar Charge Controller and Battery charge controller and are easily understand by comparing both-

In battery charge controller: –

- When battery is fully charge, battery is totally disconnected from converter.
- We can start charging of the battery any time between two fixed point voltage ranges. (i.e. 11.9v to 14.9v) by switch 1 (connect b/t pin2 & GND).
- We can stop the charging at any time below the lower voltage point of the battery. (i.e. 11.9v) by switch 2 (connect b/t pin6 & supply).



[Ref. www.google.co.in/image]

Fig. 5.8 connection block diagram of solar charge controller

In solar charge controller: –

- We can't disconnect the battery from converter because MPPT circuit is working according to battery voltage. If battery is full charged and we want to supply any dummy load then we can't because MPPT will not switch the converter due to battery is full charge
- We can't control the charging and discharging action of the battery.

Chapter 6

1Φ Inverter for Proposed system

6.1 Overview on 1Φ Inverter

6.2 Proteus Design of Proposed 1Φ Inverter

6.3 Hardware Implementation of 1Φ Inverter

6.1 Overview on *1Φ* Inverter

In any solar power generation system one of most important section is converting generated DC power to AC power for running or operating or working of the AC loads. A device called Inverter that convert DC power to AC power.

In this earth more than 90% electric equipment are driven by AC, we called it as AC loads that is proved by just watching surround us every electrical equipment are working by consuming AC power. So for using them we must required AC power even for small to very small load, AC power is required either it is grid connected system or isolated system. If we want in isolated system many loads should be DC load for that we have to specially order to the manufacturing company that will increase our expenditure then it is better to purchase AC electric equipment from market that will reduce much more our cost for electric appliances. So when loads are AC then AC power must required and for that we have to convert solar DC power to AC power that's way an inverter is an important part of solar power generation. It doesn't depend on what kind of system it is. By seeing figure 6.1 it will very clear and position of inverter in the system will also be clear.

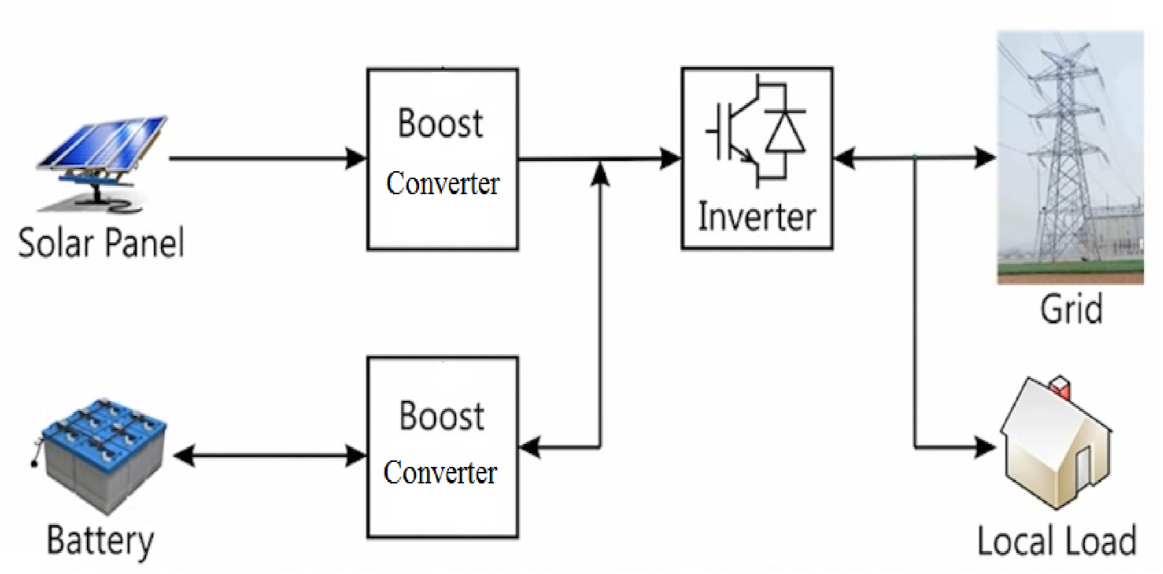


Fig. 6.1 Inverter Position and importance

Types of Inverter:-

According to the usability the inverter can divide into two categories-

1) **Isolate or stand alone inverter** - in this type inverter takes only DC power from source like battery or solar pane and convert that power into AC power and supply the AC load.
2) **Grid connect inverter –** in this type inverter sometimes take energy from DC power supply and convert it into AC power and supply to the grid and sometimes it takes energy from grid and charge the battery when DC source (solar power) is not available.

In this project a very simple compact in size single phase solar inverter is designed and implemented. A very simple and compact size is designed due to this project is mainly focus on design and implement cost effective solar power generation system to make it easy in behavior to use renewable energy sources. This design is much lookalike solar micro inverter.

6.2 Proteus Design of Proposed 1Φ Inverter

Figure 6.2 showing the Proteus design of simple solar inverter using 555 Timer IC for generating square wave with time period of 0.02 second that is 50Hz in frequency to switching the mosfet IRFZ44N [22]. In that circuit two N-channel mosfet is used for sequentially switching to provide the path for DC current flows through the transformer. Transformer rating is 230/ 2x12 V; the secondary of the transformer is two winding 12 volts each. Transformer is must chose according to load ratings.

555 Timer IC is connected in Astable mode for continuously generating square wave of frequency 50Hz. The generating frequency can be adjusted by resistor R2 and capacitor C2. The output of the 555 Timer IC is directly given to the any one mosfet and other mosfet is given by 180^0 phase shift that is logical inverted with the help of BC549 transistor as shown in figure 6.2.

As the transformer secondary have two winding, middle terminal is supplied by 12 volt battery that may in the range of 11 volt to 14 volt and other two end terminals are connected to the mosfet. This mosfet IRFZ44 can be used up to 200W loads. The transformer primary AC voltage output wave form across the 100 ohm load is shown in figure 6.3.

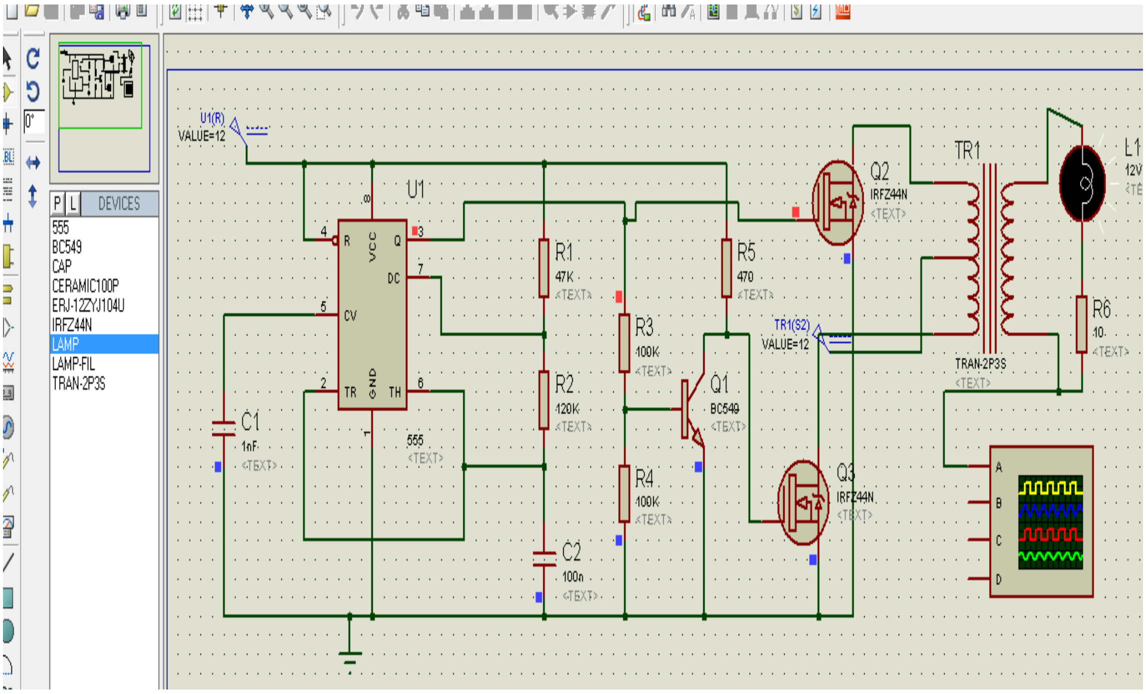


Fig. 6.2 Propose design of Solar Inverter

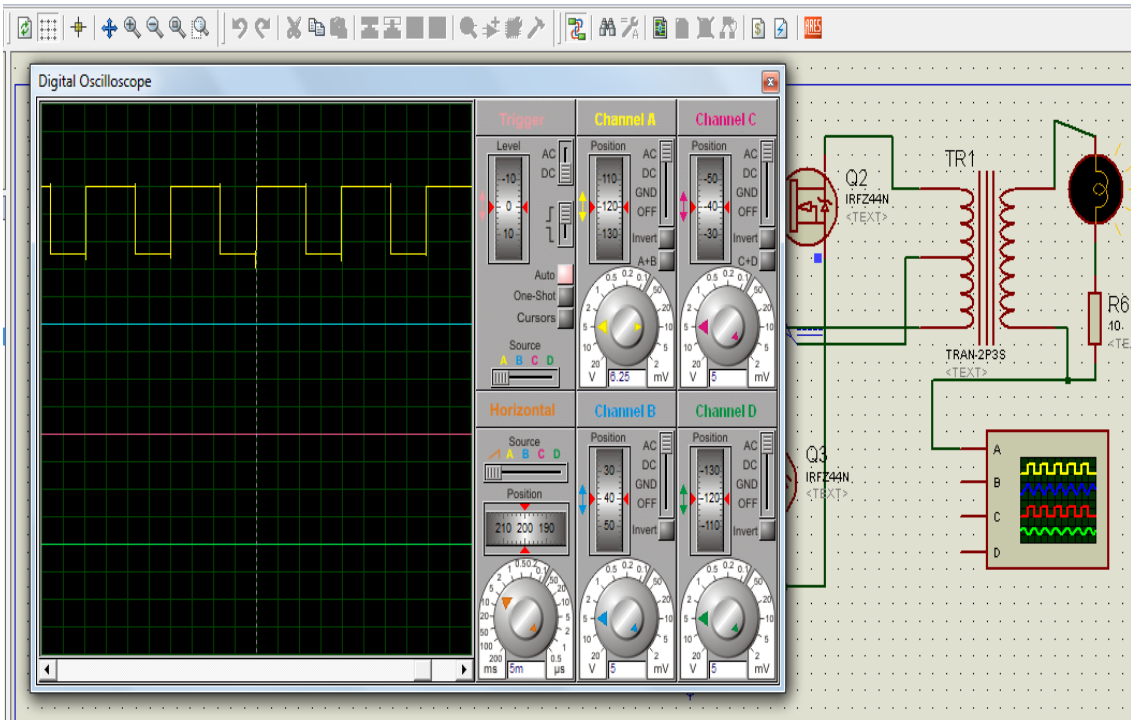


Fig. 6.3 AC Output Voltage wave form of inverter

This inverter has non stabilized square wave output voltage of frequency 50 Hz. That can supply small electrical appliances like fluorescent lamps, radios, electric shavers, and cell phone charger. The maximum load depends on the transformer ratings, transistors, and the size of its heat sink [21].

6.3 Hardware Implementation of 1Φ Inverter

Its hardware implementation is down and checked in brad board after that implemented on PCB by connecting elements as shown in its circuit diagram as designed in Proteus Software. The hardware implementation diagram is shown in figure 6.4

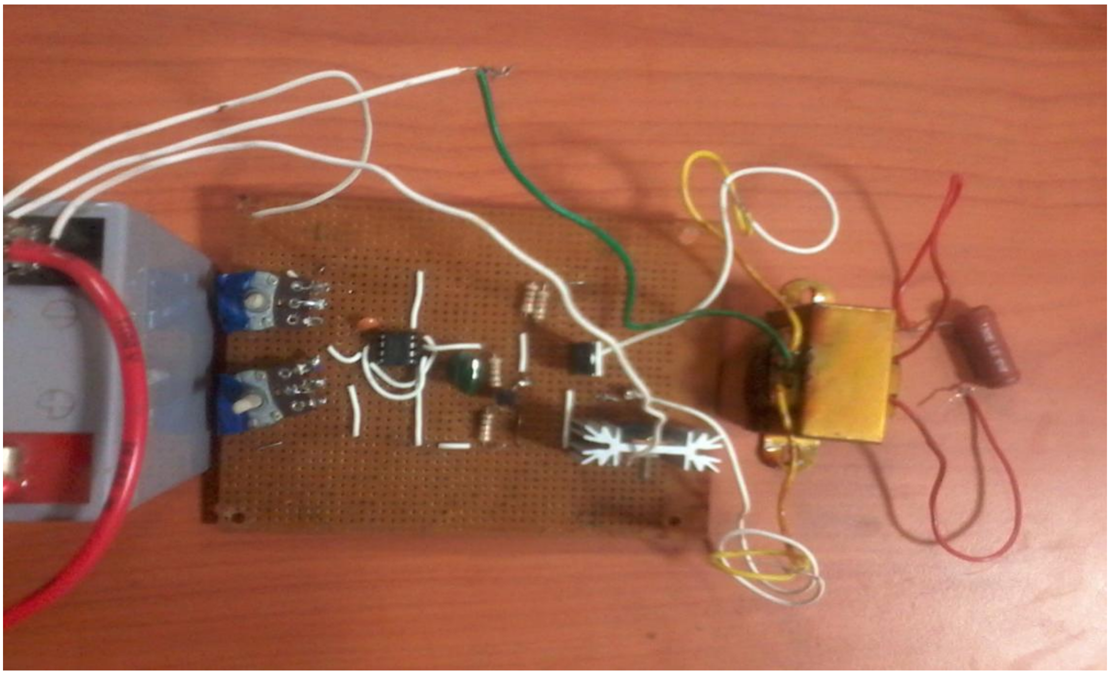


Fig. 6.4 Square Wave Single Phase Inverter

One 12 volt battery is supplied to the circuit as well as transformer middle terminal. The other two end terminal is connected to the two mosfet's drain terminal individually and their source terminals are connected to ground or battery negative terminal. Any one mosfet can be directly connected to the 555 Timer IC output pin number 3 and other one should be connected through BJT as in here BC548 is used.

In this type inverter circuit 555 Timer IC is used as Astable multi-vibrator mode to generate switching signal for mosfet. Here two variable resistors are used in 555Timer IC Astable mode circuit connection for generating desired frequency signal by varying them and choosing the accurate value of capacitor.

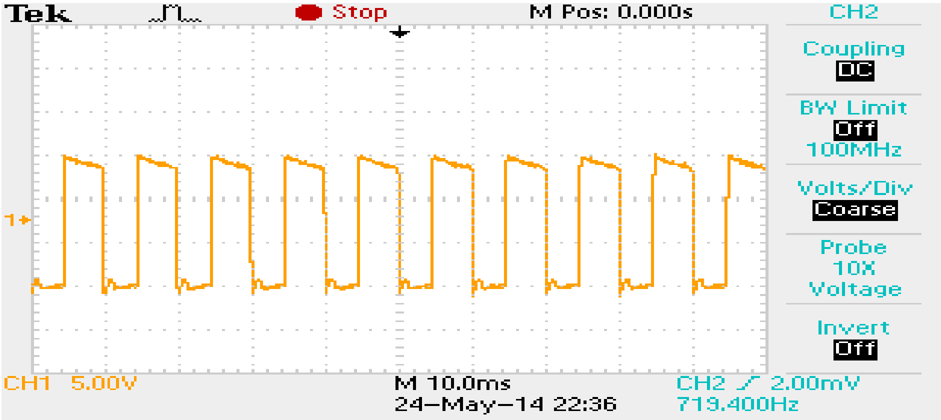


Fig. 6.5 Output Voltage Wave form of 1φ Inverter

Figure 6.5 showing the voltage wave form output across 150 ohm load of ½ Watt. This wave form is square due to 555 timers IC switching continuously both mosfet alternatively to provide the path for grounding for 12 volt DC from transformer terminals. Due to that another side of transformer voltage direction is continuously changing and making square wave as shown in the figure 6.5, the transformer should be step up so that voltage will be high at another side.

That square wave can be make sine wave by using RC filter. But the frequency may change that we have to take care and design the filter according to that so the net output wave form of the filter should have50 Hz. By using the RC filter that square wave form is changed into sine wave as shown in figure 6.6.

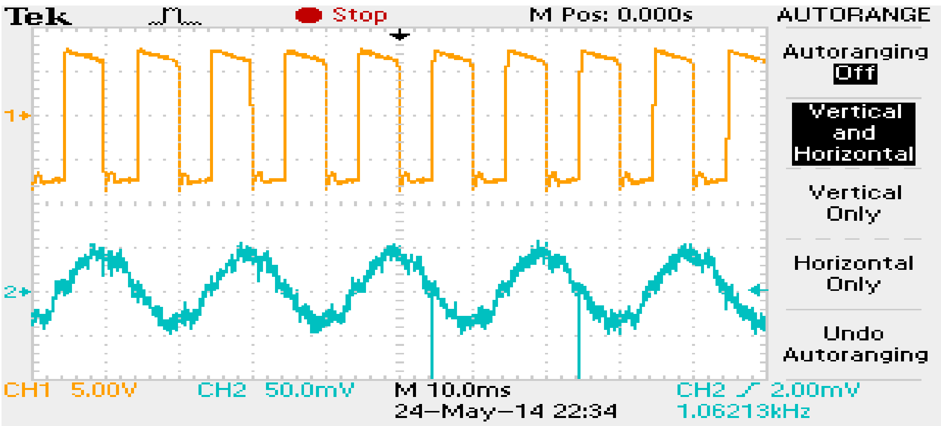


Fig. 6.6 Output Voltage Wave form of 1φ Inverter with RC filter

Chapter 7

Conclusion and Scope for Further Work

7.1 Conclusion

7.2 Scope for Further Work

7.1 Conclusion

In this project a simple low cost but effective solar PV power generation system for small and not grid connected load up to 5 KW prototype model is designed in Proteus software and implemented except solar panel that is not implemented only achieved its characteristics by designing in Proteus of Vikram solar Eldora 37W series.

While the designing of MPPT portion especially code writing for its algorithms execution is very difficult. MPPT algorithms are straightforward simple enough, but implementing an operative MPPT controller isn't a simple task. Many papers written on this subject they merely use the computer simulations output rather than real hardware outputs, the readers ascertain that actually lacking of significant data and information. Hall Effect base current sensors are very efficient, simple in connections and easy in use but it is little bit expensive in the India only. For MPPT circuit implementations always have to use complete development board kit for microcontroller otherwise its circuitry will complex and less efficient.

In all DC-DC converters boost have additional advantage that if suppose MPPT circuit is fail then mosfet will not switching in that condition also load is directly connected to the panel and panel still supply the load at less efficiency other DC-DC converter can't do that.

In the market various type of battery charge controller is available but in this thesis proposed battery charge controller has a relay that automatically switch the power from battery supply to other load when the battery is full charge.

Proteus software is better choice than Matlab for electrical circuit designing because these days many hybrid component are available in market, Proteus provide that components with their technical names as well as by its technical codes like 555 Timer IC and other integrated chips that are not available in Matlab library and Proteus also provide the facility that we can operate the switches or sliding device on executing time so that we can see and analyze the changing waveforms but in Matlab once we run we can’t change anything until its execution completion.

7.2 Scope for Further Work

Further work in this area may use different MPPT method and modified algorithms for increasing efficiency in fast changing environmental conditions. Try to design such model for solar PV system which should compact size and cheaper and also its maintaining and operating cost should be less so that people attract to use in behavior and don’t go for conventional sources even for isolated systems. Inverter should be design by using SMPS circuits if further implementation will happen from this project. Over all physical implementation of the system will remains for the future research

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